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Human Engineering and Human Resources Management in Mining

Proceedings: Bureau of Mines Technology Transfer Seminar, Pittsburgh, PA, July 7–8, 1987; St. Louis, MO, July 15–16, 1987; and San Francisco, CA, July 21–22, 1987

Compiled by Staff, Bureau of Mines

UNITED STATES DEPARTMENT OF THE INTERIOR

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PREFACE

This Information Circular summarizes recent efforts by the Bureau of Mines to reduce accidents and improve performance in both surface and underground mines through research on the human factors-ergonomics aspects of mining. The 18 papers contained in this publication were presented at a 2-day Bureau of Mines technology transfer seminar on human engineering and human resources in mining during July 1987 at three locations. The work presented represents only a small portion of the research currently being conducted by the Bureau to improve the health and safety of mine workers and to boost mine productivity through the development of more effective, efficient mining technology.

Information about other research programs or about technology transfer activities sponsored by the Bureau to introduce completed research to potential users, may be obtained by writing the Bureau of Mines, Branch of Technology Transfer, 2401 E. Street NW, Washington, DC 20241.

CONTENTS

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

deg	degree	L/min	liter per minute
deg/s	degree per second	min	minute
°F	degree Fahrenheit	mL	milliliter
fc	footcandle	(mL/kg)/min	milliliter per kilogram per minute
fL	footlambert		
ft	foot	μV	microvolt
ft•lb	foot pound	pct	percent
gal	gallon	s	second
h	hour	st	short ton
in	inch	st/d	short ton per day
kcal	kilocalorie	st/h	short ton per hour
kcal/min	kilocalorie per minute	V	volt
lb	pound	yr	year

HUMAN ENGINEERING AND HUMAN RESOURCES MANAGEMENT IN MINING

Proceedings: Bureau of Mines Technology Transfer Seminar, Pittsburgh, PA, July 7–8, 1987; St. Louis, MO, July 15–16, 1987; and San Francisco, CA, July 21–22, 1987

Compiled by Staff, Bureau of Mines

ABSTRACT

The Bureau of Mines human factors research program is directed toward reducing accidents and improving the overall efficiency of the person-machine environment interface found in surface and underground mines. The focus of the human factors program therefore, is to insure that sound knowledge is available concerning human capabilities and limitations, and that this knowledge is applied to the design of mining equipment, work tasks, and management procedures.

The papers presented in these proceedings summarize some of the recent Bureau research in human factors. The papers focus on two broad areas, human resource issues and human engineering of equipment, tools, and work procedures found in mines.

INTRODUCTION

For more than 75 yr the Bureau has been engaged in efforts to reduce mining fatalities and injuries. The success of these endeavors can be readily grasped by observing the almost uninterrupted decline in mining injuries over this extended period. In the early part of the 20th century, 2,000 or more mining fatalities occurred annually; the greater portion of these were due to mine explosions and fires. In 1986, 124 fatalities were reported and none were due to catastrophic explosions and fires.

Mine disasters, while now relatively rare, still capture the public's attention, and by any standard are tragedies deserving of every effort to prevent their recurrence. However, the fact remains that today most mining accidents that result in death or injury are single occurrences and are often associated with human performance factors. Williard Stanley, Kentucky Commissioner of Mines and Minerals, writing in *The Scoop,* v. 1, No. 11, said:

> "The basic principles of. . .mining in relation to the environment have been the same for many years and we have learned to a great extent how to make a. . .mine a safer place to work. Now we must control the human element. Since what we do or fail to do causes 90% of all accidents. . . ."

Even though this percentage estimate might be debated, most knowledgeable mining officials agree that human performance is a significant factor in mining accidents. Too often, though, inadequate or inappropriate performance is attributed to individual volition and dismissed as human error. This circumstance gives the appearance of providing an explanation for causes of human behavior without really doing so. When individuals commit errors there are natural causes for these mistakes, and the appropriate course of action is to seek to discover these causes and institute countermeasures based on sound scientific information. For example, operator compartments on some pieces of equipment are so designed that operator errors and injuries are probable. Also, management practices in some companies may, at times, provide insufficient motivation for a safe and effective workforce, and may even be inadvertently perceived by individuals as encouraging risk taking.

The Bureau's human factors research program is directed toward researching the causes of accidents, injuries, and productivity problems that are related to the human element. The following 18 papers summarize some of the recent Bureau research in this area. The papers cover a broad area and are intended not only to provide the mining community with useful data for immediate application to mining situations but also to stimulate fresh thinking on new ways to approach very old problems. The papers focus on two broad areas, human resource issues, or topics related generally to management practices; and human engineering of equipment, tools, and work procedures found in mines.

AN ANALYSIS OF SELECTED BACK INJURIES OCCURRING IN UNDERGROUND COAL MINING

By Thomas G. Bobick,[1] Terry J. Stobbe,[2] and Ralph W. Plummer[3]

ABSTRACT

Musculoskeletal injuries are a constant problem in the underground coal mining industry. Back injuries represent the largest single category of lost-time injuries. Traditional attempts to address the problems consist of compiling statistics from standard accident report forms to identify the jobs and activities that caused the back injuries. This research project, which is sponsored by the Bureau of Mines and conducted by West Virginia University (WVU), is conducting back-injury investigations that are more comprehensive than the traditional methods. Arrangements have been made with six coal mining companies in four States to call WVU when a back injury occurs. A thorough investigation is conducted by WVU personnel within a few weeks to document the environmental, biomechanical, behavioral, and task-related variables associated with the injury. Interviews with supervisory and safety department personnel are also part of the investigation. Results from 100 accident investigations are presented.

INTRODUCTION

SCOPE OF THE PROBLEM

Underground mining involves a great deal of manual handling of parts, supplies, and equipment. As the amount of manual handling increases, the potential for a lost-time injury also increases. These injuries usually involve the musculoskeletal system of the worker. Musculoskeletal disorders are a leading cause of work-related injuries in the mining industry. These types of injuries are usually classified as sprains and strains. In 1983 and 1984, sprains and strains represented 24 and 25 pct, respectively, of all lost-time injuries in the underground coal industry (*1*).[4] The corresponding 1983-84 average days lost per lost-time sprain and strain injury were 19.0 and 21.5.

The most serious type of sprain and strain injury involves the lower back. In 1983 and 1984, accident statistics indicate that injuries to the back represented 55 and 54 pct of all lost-time sprain and strain injuries. Injuries to the knees, which represented about 11 pct for each year, was the second most common body part injury in underground coal mining.

Considering severity, knee injuries have a higher number of lost days associated with them than back injuries (29.1 versus 19.3 days), but the total number of lost workdays for all back injuries greatly exceeds the total number of lost days for all knee injuries by a factor of greater than 3 (26,500 versus 8,600). Although knee injuries are more severe than back injuries (6 work weeks off versus 4 work weeks) there were almost five times the number of lost-time back injuries (1,450 versus 300). Thus, when considering the total impact on the industry, the community, and the families, worker back injuries represent a ubiquitous problem for all sectors of underground coal mining.

OVERVIEW OF THE PROJECT

In an effort to assist in controlling the ever-growing back injury problem, the Bureau initiated a multifaceted approach. This included starting a comprehensive in-house effort to research a variety of factors relating to low back pain of underground coal miners. Various aspects of the in-house work are discussed in two other papers in this Information Circular.

In addition to the in-house research program, the Bureau funded an effort to conduct a thorough investigation of accidents that involve a back injury at mining companies that agreed to cooperate with the research. Non-lost-time incidents were also investigated.

The scope of the research contract[5] is to determine if a relationship can be identified among the workers, the materials handled, the tasks that have to be conducted, and the environmental conditions, with respect to the occurrence of back injuries in the underground coal mining industry.

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[3] Professor, Department of Industrial Engineering, West Virginia University, Morgantown, WV.

[4] Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this paper.

[5] J0348044, "Research Study of Back Injuries in Underground Coal Mining," West Virginia University.

METHOD OF DATA COLLECTION

BACKGROUND

Analogous to infectious diseases, occupational low-back injuries can be treated once they occur, but the concept of immunization (i.e., preventing them from occurring initially) is more important. The science of epidemiology is defined as the study of the distribution and determinants of diseases and injuries in human populations *(2)*.

Epidemiology is used to identify common characteristics and factors, which initially may be seemingly unrelated, that may have statistically significant effects related to the occurrence of diseases, including occupational injuries. Early work in this field included classic studies related to the occurrence of scurvy in sailors, and smallpox and cholera epidemics *(3)*. Presently, epidemiology is the cornerstone of studies that have helped to identify the risk factors related to stroke (the Framingham study) and, of course, the finding of the cause of Legionnaire's disease. In the previous examples, a specific agent caused the affliction, such as the lack of citrus fruit in the diet, the highly infectious pox virus, or the polluted drinking water.

Similarly *(4)*, "the primary agent causing [occupational] injuries is energy. Control efforts are aimed at reducing its release to the body in dangerous amounts." This concept of an overdose of energy applied to the musculoskeletal system is quite appropriate for the mining industry, and will be shown to be frequently involved in causing lost-time injuries.

PRESENT PROJECT

The objective of this project is to investigate, in detail, a total of 200 back injuries as they occur in the underground coal mining industry. At the time of preparing this paper, 110 accidents had been investigated. The data presented in this paper, however, will be limited to 100 injuries.

This project is being conducted with 11 cooperating mines that are located in four States (West Virginia, Pennsylvania, Illinois, and Kentucky) and owned by six companies. The majority of the mines use electric equipment, but a few of the mines do utilize diesel-powered equipment. Average seam thickness varies from less than 5 ft to more than 8 ft. Average mine employment varies from under 100 to over 600. Mining methods represented include longwall and room and pillar. No operations employing conventional mining techniques are represented in the study.

The intent of this project is to collect information related to back injuries in more detail than typically acquired in the usual review and tabulation of accident and injury statistics. Basically, the data collection consists of reviewing the accident reports and then conducting a detailed interview with the injured worker(s), their immediate supervisor(s), and a representative of the mine's safety department within 1 to 3 weeks of the accident. The interview is structured along a format designed to determine specific facts about the following areas:

1. Job- or task-related variables (posture, movement, occurrence, weight lifted, estimate of force exerted, load size, surface conditions, etc.).
2. Personnel-related variables (height, weight, body morphology, medical-incident history, work history, training and experience, injury data, treatment data, etc.).
3. Production-related variables (reason for doing task that way, alternative methods, does a standard operating procedure (SOP) exist and was it followed, if not why not, etc.).
4. Other variables not fitting into preceding areas (unique environmental conditions, unique hazards, industrial engineering (IE) methods analysis, etc.).

The interviews, which take about an hour to complete, are conducted before, during, or after the work shift, depending on the miner's availability. A copy of the interview form is presented in the appendix to this paper. Many of the companies have incorporated some of the more pertinent items into their usual accident investigation form.

There were some fears on the part of both union and management that injured miners would be unwilling to discuss their injuries with the researchers, but in fact they have been very cooperative, often going into much more detail than originally requested. At the end of the project, the data collected on these variables will be analyzed using appropriate statistical methods to determine which factors or which combination of factors may be highly correlated to the incidence of back injures.

RESULTS

As mentioned, the results of this research are based on 100 accident investigations; these were divided almost equally between lost-time and non-lost-time injuries. The following tables were prepared to provide an overview of the results being collected in this project. The first five tables are summary tables similar to those found in most typical injury reports. The sixth table presents specific aspects of one of the more interesting early findings of the research—the importance of sudden movement in the etiology of musculoskeletal injuries. The seventh table provides a more complicated analysis of selected data.

Table 1 presents data on the frequency of back injuries with respect to job classification, broken down according to lost-time and non-lost-time injuries. Of the miners interviewed, those with the job classification of general laborer suffered 22 pct of the back injuires, which made general laborer the highest incident category. Maintenance mechanics had 17 pct of the back injuries, while roof bolter operators were third with 16 pct. The next two job classifications, in terms of frequency of back injuries, were the

Table 1.—Comparison of frequency of injuries for coal mining jobs, percent

Job title	LT	NLT	Total
General laborer	13	9	22
Maintenance mechanic	4	13	17
Roof bolter operator	11	5	16
Continuous miner operator	4	5	9
Shuttle car operator	4	3	7
Supervisor	2	5	7
Conveyor belt worker	3	1	4
Electrician	3	0	3
Surveyor-rod worker	0	2	2
Longwall helper	0	2	2
Other	5	6	11
Totals	49	51	100

LT Lost-time injury. NLT Non-lost-time injury.

operators of the continuous miner and shuttle car with 9 and 7 pct, respectively. The percentage of shuttle car operator injuries agrees exactly with a previous analysis conducted on 1981 injury statistics. *(5)*.

Table 2 contains information regarding the reason the task was being performed. The most frequent reason (17 pct of the cases) was routine maintenance. Other frequent reasons for performing the tasks were routine roof bolting (10 pct), bad top (9 pct), routine haulage and routine equipment moves (8 pct each). Of the miners suffering back injuries, virtually all of them were performing tasks that they described as a normal part of their job duties.

Table 2.—Frequency of reason for task being performed when injury occurred, percent

Reason	
Routine maintenance	17
Routine roof bolting	10
Bad top	9
Routine haulage	8
Routine equipment moves	8
Routine housekeeping	6
Prevent roof and rib deterioration	5
Equipment failure	5
Resupply section	5
Moving ventilation curtain	3
Longwall move	3
Belt-line maintenance	2
Nonroutine maintenance (track)	1
Other	18
Total	100

In table 3, the activity at the time of the injury has been coded into the categories that are used in the Mine Safety and Health Administration (MSHA) reporting system. As expected, a variety of activities have caused the back injuries. Materials handling is by far the most frequent activity at the time of injury (38 pct). This agrees quite closely with previous analyses (*1*, *6*) that indicated materials handling was involved with 34 pct, 38 pct, and 35 pct of the lost-time accidents in underground coal mining in 1980, 1983, and 1984, respectively. Injuries due to timbering (8 pct) and handling roof bolts or drill steels (7 pct) account for two-fifths of the materials-handling injuries. Handling cables is the next most hazardous activity, with 16 pct of the injuries. Conducting equipment maintenance was the third most hazardous activity, the source of 14 pct of the back injuries investigated.

Table 3.—Frequency of activity at the time of injury, according to MSHA coding system, percent

Activity	
Materials handling	38
Cable handling	16
Equipment maintenance	14
Operating shuttle car	7
Roof bolting (n.e.c.)	4
Shoveling	4
Barring down rib or top	3
Walking in mine	3
Operating continuous miner	3
Entering or exiting equipment	2
Other	6
Total	100

n.e.c. Not elsewhere classified.

The following are specific activities identified for 74 of the first 100 back injuries investigated. The most striking aspect of this list is the tremendous range of events that provoked a back injury. The data in table 3 and the following list reflect the inherent shortcoming in any injury data classifying scheme—a significant loss of pertinent information about the situation that produced the injuries.

- Climbing off a machine.
- Dragging wet ventilation curtain.
- Walking backwards with hose, tripped.
- Moving continuous miner cable and water line.
- Building cribbing.
- Restocking roof bolter.
- Rolling 4-ft spool of miner cable.
- Resetting cable and water line.
- Teletram hit continuous miner.
- Drilling hole with roof bolter, slate fell.
- Shuttle car steering failed, hit rib.
- Reaching over machine side, lifting motor cover.
- Using pry bar to hold bracket.
- Lifting 4- by 8-in by 18-ft header.
- Driving shuttle car.
- Shoveling coal and slate.
- Dragging hose.
- Reaching for 5-ft length of polyvinylchloride (PVC) pipe.
- Walking downhill.
- Bending roof bolt in a hole.
- Repairing teletram differential.
- Shuttle car hit feeder-conveyor.
- Prying on gathering head motor.
- Driving shuttle car, hit bad bump.
- Removing drill steel.
- Hammering surveying spads in low coal, awkward posture.
- Turning over box of six self-contained self-rescuers.
- Pushing dust box out of scoop bucket.
- Picking up two rock-dust bags.
- Walking, stepped in hole.
- Cutting bottom with continuous miner, large jolt.
- Picking up fallen top when a new piece fell.
- Lifting oxygen cylinder.
- Lifting 5-gal bucket of bits.
- Lifting and pulling timbers through mandoor.
- Transferring toolbox.
- Handling 6-in by 16-ft I-beams.
- Reloading roof bolter with rock-dust bags.
- Lifting 7,200-V power cable.
- Bending over and standing up.
- Prying 150-lb plate out of box.
- Walking across a supply car.
- Moving crib blocks.
- Standing on roof bolter drill head to use a torque wrench.
- Lifting a steel bar.
- Rock fell while roof bolting.
- Carrying transit and tripod.
- Exiting from mantrip.
- Inserting roof bolt into hole.
- Pushing a wheelbarrow.
- Pulling a box out of the elevator.
- Picking up a bag of oil dry.
- Loading a toolbox into scoop bucket.
- Pushing rock duster into scoop bucket.
- Lifting sheave to move hydraulic cylinder.
- Helping others to move a railstop welded to large plate.
- Lifting panel cover of scoop.
- Tossing small box into elevator, twisted trunk.
- Carrying a gear in an awkward posture.

- Lifting wooden rail tie.
- Standing on roof bolter drill head to reach high roof.
- Using pry bar to move a longwall hydraulic jack.
- Removing slate from the top with pry bar.
- Carrying 5 gal of water (greater than 40 lb).
- Standing on roof bolter in high top area, fell off.
- Inspecting roof and rib.
- Taking down ventilation curtain.
- Changing scoop tire (300 lb).
- Carrying mandoor.
- Carrying rock-dust bag, stepped in hole.
- Repairing roof bolter, motor fell, pulled worker forward.
- Carrying two 5-gal cans of oil.
- Backing the continuous miner, hit hole, bad jolt.
- Disconnecting railcars.

Table 4 presents the agent associated with the injury, as coded in the MSHA system. The table indicates that no one item is dominant in the cause of back injuries. Using the MSHA coding system, 26 separate categories contained at least one entry. Thus, the other category represents 17 other items that caused a back injury. The data presented in tables 3 and 4 and the listing strongly suggest that the underlying mechanism in back injuries is extremely diverse in its nature.

Table 4.—Distribution of agents associated with back injuries, percent

Agent	
Electric conductors	16
Underground mining machine	11
Rock, coal, ore	11
Bodily motion	9
Boxes, crates, cartons	9
Drill steel, roof bolts	6
Posts, cribs, ties, timbers	5
Bags	5
Mine floor, working surface	4
Other	24
Total	100

Information on why the injured miner was performing the task is presented in table 5. In 87 pct of the injuries, it was simply a normal part of the job. The remaining 13 pct were divided somewhat equally among six other categories. Filling in for someone else and having to do the task alone both accounted for 4 pct each. In two other instances, someone else failed to perform their task properly, thus leaving a hazardous situation in which another miner was injured.

Table 5.—Reason for performing task, percent

Reason	
Normal part of job	87
Filling in for someone else	4
No one else was available	4
Someone else did task incorrectly	2
High top or bad top	1
Getting ready for visit	1
Nonroutine (6 miners lifting)	1
Total	100

Other related information that was collected was whether the task was routine or not. In 92 pct of the cases, the task was defined as routine while the remaining situations were evaluated as nonroutine. In one nonroutine instance, the top was bad and had to be removed, which created a roof height of over 10 ft. The roof bolter operator stood on the bolter machine to insert the roof bolt. When the task was completed, the operator stepped off the bolter into loose rock and slipped, sustaining a back injury. Another example of a nonroutine task involved a miner being injured while helping five others to lift and move a railcar stop so track maintenance could be accomplished. The carstop was welded to a 3/4-in-thick piece of steel that measured 3 by 4 ft and weighed over 350 lb. Basically, however, nonroutine tasks were uncommon events and were responsible for only 8 pct of the back injuries.

One of the more interesting findings of this research so far is the importance of sudden movement as a factor in back injuries. The typical scenario is one in which either the person or the load shifts suddenly and unexpectedly. This can happen while riding in a vehicle that hits a bump or collides with another vehicle, or when walking through the mine and a worker slips but does not fall, or while carrying a load that shifts suddenly. In each case, the loading on the neuromuscular system occurs in a matter of milliseconds, and either of two events results.

First, the system cannot respond with the appropriate muscular contractions to provide protection for the body (when riding); second, in the case of the nonfalling slip, the body's natural reaction to prevent the fall causes the trunk muscles to overrespond and thus overload the lower back. Numerous back injuries have been documented that have been caused by the nonfalling slipping or tripping accident. These can result in a variety of injuries—eccentric loading with muscle tears, muscle spasm, ligament damage, skeletal damage, or even disk damage. Any of these may occur alone or in combination.

Table 6 describes the frequency of sudden movements in these injuries. The existence of sudden movement was determined from the interviews, with each case discussed before coding. Coding was positive if sudden movement clearly occurred at the time of injury, questionable if it may have been a factor, and negative otherwise. A separate code was assigned to those cases where the injured party was struck by a piece of falling top.

Table 6.—Sudden movement as a factor in back injuries, percent

Category	
Sudden movement occurred	54
Sudden movement may have occurred	23
Sudden movement did not occur	17
Struck by falling top	6
Total	100

Most back injury statistics attribute the majority of the injuries to lifting, twisting, overloading, and so forth. There is definitely no question that these are major causes of back injuries, but they are not the only causes. In many cases, they are closely associated with sudden movements. For example, a lift is started, the hand slips on the load, the lifter tries to maneuver to regain control; the maneuver is not anticipated and an injury results. Another example is when carrying something, a worker's foot slips and causes a sudden change in posture, thus resulting in an excessive loading to the body.

More important is the fact that conventional coding systems do not include sudden movements in their causal coding scheme. Unfortunately, this means that sudden movements cannot be evaluated with respect to past accident reports or injury analyses. The data collected to date

in this project strongly suggest that this is a serious oversight. More than 50 pct of the injuries investigated have clearly involved some type of sudden movement that resulted in unexpected (and thus unprepared for) loads on the body. Information on sudden movements became obvious only because of the data collection methodology of this project, that is, the in-depth questioning related to these back injuries.

This paper is providing an interim summary of the research conducted thus far, as well as providing an indication of what types of analyses will be done with the completed data base for 200 injuries. Table 7 provides an analysis of injuries that involved lifting, holding, carrying, pulling, or pushing (the classic materials-handling designations). The table was developed by first sorting the data by injury agent, then by whether sudden force release was involved, and then finally by whether the task was routine or not (whether the task was done every shift or even every day by someone at the mine).

Of the 42 accidents listed in table 7, 27 involve a sudden movement loading. Of these, 23 are routine tasks and 4 are designated as nonroutine. The remaining 15 accidents do not involve any type of sudden movement loading. Fourteen of these are routine tasks and only one is considered a nonroutine task.

Table 7.—Back injuries involving typical materials and equipment, analyzed by whether sudden body movements occurred or not, and whether the task was routine or not

Materials and equipment	Sudden movement	Task routine	Number
Ventilation curtain	Yes	Yes	2
Spool of cable	Yes	Yes	1
Timbers and headers	No	Yes	1
Rock duster	Yes	No	1
	Yes	Yes	1
Scoop panel and 10-st-capacity jack	Yes	Yes	1
I-beam	No	Yes	1
	Yes	Yes	1
Wheelbarrow	Yes	No	1
	No	Yes	4
Cable and/or water line	Yes	No	1
	Yes	Yes	7
Light item, not specified	No	Yes	3
	Yes	Yes	2
Heavy item, not otherwise specified	No	No	1
	No	Yes	3
	Yes	No	1
	Yes	Yes	2
Roof bolt with or without half header	No	Yes	2
	Yes	Yes	4
5-gal containers of liquid	Yes	Yes	2

DISCUSSION

This research has identified that sudden movement, caused by a wide variety of situations, is a major cause of back injuries in underground coal mining. As mentioned earlier, the sudden release of energy to the musculoskeletal system can be classified as the primary causal agent for these injuries. Trying to prevent these injuries seems to be an extremely difficult task, considering the diverse set of activities that were listed in the "Results" section. However, just having an awareness of these types of situations can help to change an unexpected condition to an expected condition, and thus reduce the loading to the lower back, as explained in the following.

A recent research study (*7*) investigated the response of the back muscles during sudden, unexpected loading. The data collected during the unexpected loading were compared to the back-muscle response data collected (under the same test conditions) during sudden, expected loading. The data from this research study indicate that the unexpected conditions caused trunk-muscle reactions that resulted in greater loadings to the lower back than those encountered (under the same test conditions) when the loading was expected.

The magnitude of the unexpected loads averaged 1.7 times that of the expected loadings for the peak component of the muscle force, and 2.4 times the expected loading for the mean component of muscle force. These data indicate that the effect of unexpected loading essentially makes the muscles respond the same as they do to more than twice the weight during an expected loading situation. These findings indicate that if a person is aware of potentially hazardous conditions, and if some event occurs (slipping, tripping, jolt or bump, load slips in the grasp, and so forth), the body's reaction to it will be more controlled, and will result in less loading to the musculoskeletal system.

One practical idea related to the unexpected-expected loading concept can be instituted rather easily. Haulageway conditions change constantly because of the dynamic nature of coal mining. In a matter of a few weeks or less, a good haul road can be in very rough shape because of its constant use; or a haul road may have to be relocated from an entry with good conditions to an entry with poor conditions.

When rough conditions are encountered, a simple means of marking their location is to hang reflectors (or perhaps just one of a dramatic color) from a roof bolt plate. As conditions change, the reflectors can be moved or more added to mark new rough areas to alert the usual operators and to warn other operators who may be unfamiliar with the road conditions. Even a second or two of warning lets the body's natural protective mechanism tense the muscles to prevent a totally unexpected load to occur to the lower back.

This idea is adapted from a film ("Visual Search in Driving") developed for the Ohio Department of Transportation by The Ohio State University. One part of the film dealt with night driving and showed a dramatic improvement when a driver was told to make a turn at a street light in the distance as opposed to a certain cross street in the distance. The light source was easier to perceive and was a better reference point. Thus, it is apparent that a uniquely colored or shaped reflector positioned on the mine roof would serve as a warning to operators of equipment (in all sections of the mine) of hazardous bottom conditions.

In conclusion, both the miners and supervisors should be reminded to look for, identify, and consciously avoid potential sources of sudden, unexpected movement. Communicating their observations to the other miners will be helpful and quite effective in reducing the potential for these types of back injuries.

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APPENDIX—INJURED WORKER INFORMATION-OBSERVATION FORM—BACK INJURY RESEARCH PROJECT

Case # _____

ACCIDENT SUMMARY

A1. Description of accident ____

____

____

____

A2. Shift working at time of accident ____

A3. Time of accident ____

A4. What was being done at the time of injury? How? ____

____

____

____

A5. Why was task being done? How did it relate to overall activity? Was it routine? ____

____

____

____

A6. Why were you doing the task? (Normal part of job; just filling in; helping out; emergency; etc.) ____

____

A7. Is there a standard method for the task? (SWI, JSA, etc.) What is it? What related training did you have? ____

____

____

____

A8. If A4 and A7 are different, why? ____

____

____

A9. Would A7 have improved the situation? ______________________________

____

A10. Are there alternative methods for the task? Describe and evaluate. (Hoist, etc.)

Why weren't they used? ______________________________

____

____

____

A11. How many normally do the task? ______________ This time ______________

If different, why? ______________________________

____

A12. If more than one miner was involved, was (were) the other miner(s) a factor in the injury? How or why?

____

____

A13. Was the lack of communications or training a factor? ______________________________

____

A14. Does the task have any special hazards? ______________________________

____

____

A15. Was equipment involved? How? Design factors? ______________________________

____

____

A16. How could the situation be avoided in the future? ______________________________

____

____

MATERIAL HANDLING SUMMARY

B1. Describe the load (size, shape, center of gravity.) Stable? Slippery? Handles? (their shape and location, etc.). If shoveling, what is typical load? How is it handled? Shovel design?

____

____

____

B2. Where was the load? ______

At start of movement ______ At end ______

B3. How was load grasped (specify hand position) ______

______

B4. Weight ______

B5. Bottom (ground, floor) condition ______

______

B6. Obstruction(s) to movement of load ______

______

B7. Obstruction(s) to movement of body (equipment, housekeeping) ______

______

B8. Mine height at injury site (use posture-based estimate) ______

______

B9. Push? Pull? Lift? Lower? ______

B10. Handling frequency (estimate) and normalizer (per hour, per shift, per stopping, etc.) ______

______

B11. Lifting technique (normally, this time, forward or backward curve to the trunk) ______

______

B12. If not normal, why not? ______

______

B13. Body posture at time of injury (sketch)

B14. Material handling summary of current job (tasks, loading, frequency, mean, and range) ______

______

B15. Environmental conditions. Lighting ______

Noisy? ______ Describe if possible ______

Dusty? ______ Other? ______

______

B16. Working overtime? ______

B17. If yes, what was done during regular work shift? ______

______

INJURY SUMMARY

C1. Describe the injury (what did you feel, where, when—relate this to accident description) ______

______

C2. Location of pain ______

C3. Description of pain ______

C4. Examination procedure ______

______

C5. Treatment received ______

C6. Diagnosis ______

C7. Physical therapy or medication ______

______

C8. Prescription ______

C9. Injured's opinion of injury cause ______

______

PERSONAL DATA SUMMARY

D1. Age ______

D2. Sex ______

D3. Job title ______

D4. Job working at the time of the injury ______

______

D5. Experience with the task being done at the time of the injury ______

______

D6. Height and weight ______

D7. Physique and physical fitness (subjective estimate) ______

______

D8. Grip strength results R1______ R2 ______ L1 ______ L2 ______

(Circle preferred hand)

D9. Other strength results ______

______

HISTORICAL SUMMARY

E1. Mining-related work history:

Job title ______________________ No. of years ______________________

Lifting, material-handling activity ______________________

____

Job title ______________________ No. of years ______________________

Lifting, material-handling activity ______________________

____

Job title ______________________ No. of years ______________________

Lifting, material-handling activity ______________________

____

Job title ______________________ No. of years ______________________

Lifting, material-handling activity ______________________

____

E2. Nonmining-related work history:

Job title ______________________ No. of years ______________________

Lifting, material-handling activity ______________________

____

Job title ______________________ No. of years ______________________

Lifting, material-handling activity ______________________

____

Job title ______________________ No. of years ______________________

Lifting, material-handling activity ______________________

____

E3. History of all types of strains and sprains ______________________

____

____

E4. Leisure activities ______________________

____

____

ANALYSES OF MATERIALS-HANDLING SYSTEMS IN UNDERGROUND LOW-COAL MINES

By Thomas G. Bobick[1]

ABSTRACT

Task analyses were conducted by the Bureau of Mines at four underground low-seam coal mines to evaluate their supply-handling systems and for use in subsequent design of laboratory simulation experiments. Items were tracked (by videotaping) from delivery to the surface storage areas to their final destinations underground. Of particular interest were those tasks that required manual handling of supplies or equipment. Analysis of the videotapes revealed that the miners handled materials while stooped over a total of 37.8 pct of the time, 31.5 pct while on both knees, and 9.5 pct while kneeling on one knee. These working postures impose considerable stress on the lumbar spine and may be implicated in the high number of back injuries in this work population.

This paper also discusses various mechanical-assist devices developed by the Bureau and successfully evaluated in the underground workplace. These devices can be used to minimize the manual effort and the corresponding risk of injury associated with handling supplies and equipment components in low-seam coal mines.

INTRODUCTION

Underground miners who must work in low-seam coal mines (≤48-in roof height) often handle heavy materials in kneeling or stooped postures. Both of these postures are known to produce considerable loads on the lumbar spine and may be a reason for the high number of back injuries in the mining environment.

Approximately 70 pct of all miners will have some time off with back pain during their career *(1)*.[2] Approximately 25 pct of all mining injuries involve trauma to the back *(2)*. Considering severity, back injuries have an average of 19.3 lost workdays per injury *(3)*. Between 55 and 60 pct of these back injuries are due to overexertion during materials-handling activities *(3)*.

The Bureau is currently conducting an in-house project to determine the stresses associated with lifting in work postures characteristically assumed in low-coal mines. Task analyses, which were conducted in four underground low-seam coal mines, were used to design a laboratory study that simulated repetitive lifting tasks under controlled conditions.

An important support activity for underground mining is the transfer of supplies and equipment from the surface storage areas to the underground locations where they are needed. Typically, 20 to 30 pct of the total underground workforce is involved exclusively in handling supplies; however, virtually all underground miners are occasionally required to manually lift and transport parts, supplies, or equipment. The techniques for handling supplies in the underground environment, whether manually or mechanically, can vary extensively depending on the environmental conditions, the available equipment, and current management practices.

To identify the various factors that characterize the materials-handling problems, a task or job analysis is necessary. Job analysis has been defined *(4)* as "a method of gathering pertinent facts about worker[s] and [their] work. The method to be used varies, depending upon the objective of the study." A job or task analysis usually consists of a detailed listing of activities in some systematic order, generally in the sequence that they occur in the job.

Task analyses were conducted in three low-seam coal mines located in eastern Kentucky and one low-seam coal mine in central Pennsylvania. Different job classifications that required workers to manually handle supplies or equipment as part of their normal job duties were documented. The focus of the task analysis was to determine the extent to which low-seam coal miners conducted their manual materials-handling activities in stooped-over or kneeling postures.

Research has been conducted that has shown that the stooped posture increases the pressure in the disks of the

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[2]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

lumbar spine *(5-6)*. The possibility of damaging a disk increases when an individual is performing materials-handling activities with a severely bent back *(7-8)*. Handling materials while kneeling is also stressful to both the disks and the vertebras of the spinal column, because of the twisting motion that is employed in this posture *(9)*. The torsos of these workers twist because their knees cannot be easily repositioned to prevent trunk rotation.

Other research has indicated that twisting can cause an unsymmetrical distribution of forces on the disks of the lumbar spine *(10)*, and can actually be more hazardous to the lower back than severe bending alone *(11)*. In fact, the Work Practices Guide for Manual Lifting, developed by the National Institute for Occupational Safety and Health, suggests that a worker should never twist while lifting *(12)*. While a great deal of research has focused on developing lifting limits for unrestricted work postures *(12)*, very little research has studied the problems associated with lifting materials in restricted work postures *(13)*.

The objective of this study was to conduct a task analysis at several low-seam coal mines to document the supply-handling activities so experimental studies, which would investigate the physiological and biomechanical responses to handling materials in kneeling and stooped postures, could be designed and conducted in a realistic manner.

BACKGROUND

The National Coal Board of Great Britain refers to the analysis of the factors that affect performance of any job as work study. Work study is defined *(14)* as "the systematic examination of activities . . . to improve the effective use of human and other material resources." Many different techniques can be used to conduct a task analysis, since there is a wide variety of jobs to be analyzed. Task analysis is useful in structuring jobs, investigating accidents, defining personnel requirements, describing job duties, or developing training programs. Some researchers have listed as many as 20 major categories to which a task analysis can be applied *(4)*.

Because the underground mining environment is quite different from the typical industrial workplace, the task analyses that are utilized are unique to that industry. Many task analysis techniques used in factories or other similar work environments are not applicable to the underground environment. In a manufacturing workplace, observers can usually position themselves so they will not interfere with the job activities, and the workplace is usually well illuminated so a mobile worker can be followed and photographed fairly easily. The optimum situation is when the observer can remain unnoticed while conducting the job analysis, thus not biasing the results.

The underground mining environment, however, provides unique problems for researchers conducting a task analysis. Area illumination is provided only by the limited number of production and haulage machines. Personal illumination is provided by battery-powered cap lamps worn on hard hats. When videotape is used to film the materials-handling activities, the miners are aware of the start of taping because of the bright light required for the filming activity. Unfortunately, the use of this light, combined with the fact that the investigators could not conduct the study without being observed by the miners, may have caused the miners to alter their daily activities, thus affecting the task analysis. Efforts were made to assure the 10 or 12 miners on the section crew that the study was not a productivity study and that the results would not adversely affect their jobs. Despite these assurances, however, there was no way to evaluate whether the miners altered their work patterns to create a positive effect for management, since it was not possible to observe a control group without causing the same problem. Future studies will be conducted using more sophisticated video equipment that requires less light, thus making the presence of the investigators less obvious.

An early study funded by the Bureau *(15)* described the underground operating environment in terms of five separate supply-handling functions: (1) production end use (supply items used at the working face), (2) production supply (supplies moved from surface storage to near the working face, but excluding end use), (3) section move (handling supplies during the process of moving a production unit to a new section of the mine), (4) equipment maintenance (supplies or parts needed for maintenance of mining equipment), and (5) mine maintenance (supplies needed for permanent maintenance of the mine).

Accidents during the production supply activities represented 49.4 pct of the total accidents in the 22 mines that were visited during this early research program *(15)*. The remaining 50.6 pct of the accidents were divided among the other four categories almost equally—11.2 pct for production end use, 13.0 pct for section move, 16.4 pct for equipment maintenance, and 10.0 pct for mine maintenance activities.

There are several types of daily supplies of different weights and sizes involved in the production and mine maintenance supply functions. Table 1, which is taken from reference 15, provides a typical list of supply items and corresponding weights.

Table 1.—Weights of supplies commonly handled in underground coal mines, pounds

2- to 12-ft roof bolts, plates, and shells	4- 12
Rock-dust bags	50
2- by 6-in to 6- by 8-in, 1- to 16-ft lengths of timber, boards, and headers	8-270
16- by 8- by 4- or 6-in stopping blocks	27- 65
5-gal oil container	40
4- to 10-in-diam, 3- to 15-ft-long round timber posts	34-320
1- to 6-ft crib block	20- 60
Mortar mix bags	90

Figure 1 shows a typical supply-handling activity in low coal—a miner is ready to throw a 6- by 6-in cribbing block weighing approximately 35 lb. The kneeling posture imposes considerable torsional stress on the lower back because the workers cannot easily reposition their knees.

METHOD

A task analysis was performed at three small (two sections each) low-seam (roof heights ≤48 in) underground coal mines in eastern Kentucky during 1984 and one large (11 sections) low-seam coal mine in central Pennsylvania during 1985. Videotape was used to document the materials-handling activities of workers in these mines according to

Figure 1.—Low-seam coal miner ready to throw a 6- by 6-in cribbing block, weighing approximately 35 lb. The kneeling posture imposes considerable torsional stress on the lower back because the workers cannot easily reposition their bodies.

the previously described five major supply-handling categories.

During 24 mine visits (12 in Kentucky and 12 in Pennsylvania), an attempt was made to document as many supply-handling activities as possible given the time constraints and the availability of activities that could be filmed. A listing of most of the materials-handling tasks (broken down by supply-handling function) filmed during the Kentucky visits is provided in table 2. Table 3 provides the breakdown for the Pennsylvania mine visits. Of course, these are the tasks that the survey crew was able to document during the mine visits. This does not imply that these tasks are more important than others that might not be listed. Often the crew would be just a little too late or too early to videotape other equally important manual-handling tasks.

Table 2.—Supply-handling function tasks filmed at three Kentucky mines

Function	Task
Equipment maintenance	Removing continuous miner gathering arm motor.
Section move	Advancing conveyor belt.
Production end use	Hanging ventilation curtain.
	Throwing rock dust.
	Handling or pulling power cables.
	Setting timbers.
	Installing roof bolts.
Production supply	Unloading roof bolts and plates.
	Loading and unloading concrete blocks.
	Loading and unloading rock-dust bags.
Mine maintenance	Installing heavy wooden roof-support beams, 10- by 10-in by 12-ft.
	Installing 16-ft I-beam.
	Installing roof-support cribbing.
	Building concrete block ventilation stopping.

Table 3.—Supply-handling function tasks filmed at one Pennsylvania mine

Function	Task
Equipment maintenance	Removing servopump from continuous miner.
Section move	Advancing conveyor belt.
Production end use	Throwing rock dust.
	Setting timbers.
	Installing roof bolts.
	Handling or pulling power cables.
Production supply	Loading rock-dust bags onto supply cars.
	Loading timbers into scoop from supply car.
	Loading roof bolts and resin onto small scoop.
	Unloading roof bolts and resin at face area.
	Unloading rock-dust bags.
Mine maintenance	Building a concrete block ventilation stopping using both 65-lb solid blocks and 27-lb hollow core blocks.
	Laying rail; moving rail into place by manually sliding and by using a pry bar.
	Unloading and carrying 3- by 8-in by 18-ft-long wooden planks for roof control.
	Installing a series of roof-support cribbings.

GENERAL DESCRIPTION OF THE SUPPLY-HANDLING SYSTEMS

The equipment used to handle supplies at these mines included battery locomotives and tractors, scoops and mine jeeps, rail-mounted and rubber-tired flatcars and trailers, and shuttle cars. The production supply activity observed in these task analyses indicated that two distinct systems were utilized. The methods used were different mostly because of the size of the mines.

The three mines in eastern Kentucky were all small operations that consisted of only two continuous miner sections in each mine, and operated two shifts per day. The midnight shift was strictly for maintenance. The mine in central Pennsylvania consisted of 11 production sections; 1 of these was a longwall operation and the other 10 were continuous miner sections. This mine operated three shifts a day, with maintenance being conducted whenever it was needed. A spare section was available and could be put into operation if another section was down for a long time because of extensive maintenance.

The surface supply yards at the three small mines were, to some extent, unorganized and mismanaged. A forklift was available at one supply yard, but the rough terrain and the haphazard layout of the yard usually made its use impossible. In fact, the task analysis crew observed two workers manually rolling a large wooden beam (10 by 10 in by 12 ft, 250 lb) onto the forks because the forklift could not remove it from the storage pile that was in disarray. Thus, supplies were generally loaded and unloaded by hand.

Concrete blocks and rock-dust bags were delivered to the surface storage area unpalletized. These items often had to be handled twice before they were loaded onto the supply train to go underground. Because the company had only a limited number of supply cars, they had to be unloaded at a central location so the empties could be taken back to the surface for reloading.

Unloading of the supplies was accomplished manually by two workers. To move the supplies from the central storage area to the end-use location, they were reloaded onto a scoop vehicle (which could unload them mechanically with the pusher plate of the bucket) or a shuttle car from which the supplies had to be manually unloaded. Thus, each block or bag was manually lifted and lowered four or five times; this unnecessary handling increases the risk of

musculoskeletal injuries to the miners and, of course, materials breakage and waste.

In contrast, the surface supply yard at the central Pennsylvania mine was very organized and well managed. The physical layout of the supplies facilitated the use of forklifts or front-end loaders to handle virtually all supplies by mechanical means directly onto the supply train. There were, however, some instances when some supplies had to be manually handled. The most notable exceptions were the rock-dust bags and supplies like wooden planks, crib blocks, and bundles of wedges that had to be rearranged and leveled off in the supply cars so the pile would be more stable or other items could be laid on top of them.

The rock-dust bags were delivered to the storage yard by tractor-trailer at least once a day (often twice a day). The number of bags ranged from 600 to 800 per load. Two workers unloaded them directly onto two supply cars. Because this was a large mine, extra supply cars were available. Thus, cars could be left on a rail siding in each production section. As supplies were needed, the supply workers would use the scoop vehicle to transport supplies from the rail siding to the face area. Rock-dust bags would then be handled only twice from the surface to the end-use locations. The potential for an injury to a worker or breakage to the bags was, therefore, reduced by 50 to 60 pct of that at the smaller mines that had to constantly reuse their supply cars.

In addition to videotape, other techniques used to gather information on manually handling supplies at these mines involved interviews, on-site observations, still photography, and analysis of previous accidents.

The videotapes were analyzed to determine the postures used by low-coal miners for the various underground materials-handling tasks. Additionally, an analysis was conducted of the frequency (lifts per minute) of the materials-handling tasks that involved repetitive handling of loads, using the tasks documented on videotape. Results from these two analyses are presented in the following section.

During the visits to the mine sites, permission was received to collect data from the accident reports pertaining to back injuries that occurred during the previous year. Information was collected on back injuries that occurred at the Kentucky mines during 1983 and at the Pennsylvania mine during 1984. Subsequently, an analysis was conducted to determine the percentage of these accidents that involved materials-handling activities at a low lifting frequency (≤4 lifts/min), and those accidents that involved a high lifting frequency (>4 lifts/min).

RESULTS

The results of the videotape analysis on postures utilized during underground materials-handling activities in the four mines are presented in table 4. The predominant posture used while handling materials in these mines was stooped over (37.8 pct of total time on videotape). Kneeling on two knees was used for handling materials in 31.5 pct of all the videotaped materials-handling activities. Quite surprisingly, the next most often utilized posture was standing (13.4 pct), which was a result of the seam conditions encountered in the Pennsylvania mine.

The average seam thickness in the Pennsylvania mine ranged from 41 to 47 in. There were, however, numerous areas in this mine where work was conducted when the seam thickness increased or when bad top was being stabilized and supported. For example, over 35 pct of the total time videotaped of the Pennsylvania miners working upright (standing) was related to the installation of roof-support cribbings. Other activities in which these workers were standing were track maintenance activities and roof bolting.

The three Kentucky mines were operating in coal seams that were 36 to 42 in thick. Because of this more restricted posture, the miners worked while kneeling on two knees considerably more often than they did in the stooped posture. Conversely, the Pennsylvania miners tended to take advantage of the extra clearance they had and spent considerably more time working in a stooped position than while kneeling.

Table 5 presents data regarding the frequency of lift for various materials that require repetitive handling. As shown in this table, the highest frequencies were for unloading concrete block from a supply car (approximately 16 lifts/min) and unloading roof bolt plates, two or three at a time from a supply car (approximately 15 lifts/min). Handling rock-dust bags and cribbing block averaged about 10 to 11 lifts/min, and unloading roof bolts and handling

Table 4.—Time on film of postures assumed, during all manual-handling tasks, percent

Posture	Kentucky[1]	Pennsylvania[2]	Weighted average[3]
Stooped	23.2	46.7	37.8
2 knees	53.3	18.1	31.5
Standing	5.6	18.1	13.4
1 knee	12.9	7.4	9.5
Sitting	3.1	8.1	6.2
Squatting	1.8	1.5	1.6
Total	[4]99.9	[4]99.9	100.0

[1] Based on 167.6 min of videotape.
[2] Based on 273.8 min of videotape.
[3] Based on 441.4 min of videotape.
[4] Does not add to 100 pct because of independent rounding.

Table 5.—Lifting frequencies associated with repetitive tasks

Supplies	Time per lift, s: Mean	Time per lift, s: Range	Approx lifts/min
Unloading supply car:			
Roof bolts	9.12	7.35-13.15	6- 7
Rock-dust bags	5.27	4.99- 5.41	11-12
Roof bolt plates	3.92	3.19- 5.10	15-16
Concrete blocks	3.74	3.42- 4.08	16
Building ventilation stopping:			
Handling concrete blocks	9.91	8.19-14.40	6
Building roof-support cribbing:			
Handling wooden crib blocks	6.12	4.84- 6.92	9-10

concrete blocks during the building of a ventilation stopping averaged about 6 to 7 lifts/min.

Results of the analysis of accident records for the eastern Kentucky mines are presented in table 6. Of the 27 back injuries that occurred at these mines during 1983, 48.1 pct were caused by lifts requiring heavy static exertions, 33.3 pct were caused by repetitive lifting tasks, and 18.5 pct were not the result of lifting activities.

Table 6.—Summary of accident records: Handling materials and back injuries at an eastern Kentucky coal company, 1983

Category	Injuries	Share of total, pct
Heavy static exertions	13	48.1
Repetitive lifting	9	33.3
Other (struck by, struck against, etc)	5	18.5
Total	27	[1]99.9

[1] Does not add to 100 pct because of independent rounding.

DISCUSSION

Several manual-handling activities were identified on the videotapes that could be either eliminated or modified to reduce the potential for a back injury. Examples include manually unloading roof bolts, and manually lifting and holding heavy roof-support beams.

Roof bolts were delivered to one of the three Kentucky mines in wire-wrapped bundles of 500 bolts. These were loaded on the supply car (on the surface) by a forklift. The wire straps were then cut to allow the bolts to spread out so they could clear a low-roof area of the mine along the main haulageway. However, this meant that the bolts had to be manually unloaded underground, three or four at a time. What would have been a 1-min task using mechanical means (a chain attached to the scoop bucket) was turned into a 15- or 20-min task that involved lifting, twisting, and potential pinching hazards. The Bureau's recommendation was to contact the vendor and request that the bolts be delivered in bundles of 200 or 250. The smaller bundles could then clear the low area along the haulageway. Thus, the bolts could remain strapped together, permitting the workers to use the scoop to pull the bundles off the supply car to the section storage area, saving time and eliminating manual handling.

Many of the more hazardous manual-handling tasks occur during mine and equipment maintenance. In an attempt to address these problems, the Bureau has designed and fabricated specialized mechanical-assist devices to help with the more difficult jobs. Each device is relatively inexpensive and can be built in any reasonably equipped mine shop. This should encourage a company to fabricate enough of the devices to be generally useful. Three of the devices developed thus far include the following.

1. *Mine jack-wheel changer.*—This device (fig. 2) is the underground version of the floor jack found in most surface maintenance shops. High-flotation tires provide quick transport and positioning in wet or rocky bottom, and the fore-and-aft and rotational adjustments of the saddle permit easy alignment of the bolt holes. With a jack of this type, a shuttle car tire, a motor, or a transmission can be removed and replaced with a minimal amount of manual handling.

2. *Pivot boom.*—This device (fig. 3) is an adaptation of a common device found on many pickup trucks. It can be used to drag, lift, and position (swing) loads weighing up to 500 lb that are adjacent to any machine.

3. *Beam-raising vehicle.*—I-beams, sections of rail, and heavy wooden crossbeams are often installed in haulageways that need extensive roof support. The wooden beams, ranging in size from 8 by 8 in to 12 by 12 in, with lengths varying between 10 and 16 ft, can weigh from 200 to 300 lb. The sections of rail are usually 15 ft in length, and the size used will vary from 80 to 105 lb (per 3-ft length). Thus, the total weight of a section of rail can range from 400 to 525 lb. The I-beams used for this type of roof support will typically weigh as much as the sections of rail.

During the mine visits in eastern Kentucky, videotapes were taken of the installation of two 10- by 10-in by 12-ft wooden beams and a 6-in I-beam, approximately 16 ft long. These were both lifted and manually held until the support timbers were installed at each end. The wooden beam was lifted by three workers, two at one end and a single massive employee who supported the other end on his back while he was bent over in a stooped posture. The I-beam was lifted and supported by five workers.

As a result of these observations, two Bureau researchers designed a special vehicle (fig. 4), which can be either rail-mounted or equipped with rubber tires, that uses a movable hydraulic jack to safely lift crossbeams, I-beams, or sections of rail to the mine roof and position them for permanent installation (fig. 5). The hydraulic jack is recessed into the vehicle so that it can serve as a regular flat car for hauling supplies when it is not being used for beam installation. Additionally, the jack can be rolled back and forth along the length of the car while the jack arm is in a raised position. This permits the positioning of the beam to its proper location without moving the entire car.

The end of the arm that supports the beam can be rotated through 360° in a horizontal plane (parallel to the floor and roof). The capability of rotating the beam-support head increases the ease with which the heavy, awkward beams can be maneuvered. Essentially, this device will permit the beams to be safely installed by only two workers—one to balance the beam on the support head and the other to operate the jack to raise the beam to the roof. This vehicle is presently being field tested in an eastern Ohio coal mine (fig. 5) where it has been favorably received and has been used regularly for the past year.

The majority of the supply-handling tasks, however, are of such a nature that individual items are handled repetitively. It is these types of tasks, such as handling rock-dust bags, concrete blocks, or wooden crib blocks, that are serving as the basis for simulation experiments in the Bureau's ergonomics laboratory. Laboratory simulation allows controlled biomechanical, physiological, and psychophysical evaluation of the tasks; thus, an indication of the strenuousness of the activities can be determined.

The task analyses conducted at four mines indicated that underground miners typically work in a stooped-over posture, or while kneeling on both knees. Therefore, the ongoing laboratory research has been designed to look at the physiological effects on low-seam coal miners as they lift in stooped and kneeling postures under controlled conditions.

Figure 2.—Prototype mine jack-wheel changer during capacity testing with a 1,500-lb block.

Figure 3.—Underground testing of the pivot boom, which has a 500-lb lifting capacity.

Figure 4.—Shop testing of the beam-raising vehicle.

Figure 5.—Installation of a 15-ft section of rail (weighing 525 lb) in an eastern Ohio coal mine.

SUMMARY

The task analyses, which were conducted on the supply-handling systems of the different cooperating mines, indicated the importance of having a systems approach (handling palletized or unitized supplies) to the movement of materials. The videotapes were valuable for defining and analyzing the postures that the miners assumed while performing their normal daily routine. The task analysis was a necessary step in designing the experiments that are being conducted in the laboratory. Analysis of the tapes indicated that approximately 15 to 20 pct of the manual-handling tasks could probably be eliminated or modified by existing or easily designed and fabricated mechanical-assist devices, such as the Bureau-designed beam-raising vehicle, which if used to lift and assist in the installation of heavy roof-support beams could prevent potential back injuries.

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BACK STRENGTH AND LIFTING CAPACITY OF UNDERGROUND MINERS

By Sean Gallagher[1]

ABSTRACT

The Bureau of Mines is conducting research to establish recommendations for reducing the incidence and cost of back injuries due to manual materials-handling (MMH) activities in low-seam coal mines. Typically, 55 to 60 pct of all back injuries suffered in the mining industry are a result of overexertion during manual lifting tasks. While many lifting studies have been performed relating to other industrial environments, few studies have addressed the unique stresses of lifting in the low-coal mining environment.

This paper summarizes Bureau research that has examined the physiological, biomechanical, and psychophysical stresses associated with lifting in the restricted working postures used by miners in low-coal mines. The implications of the findings of these 2-yr studies are discussed, and preliminary recommendations for lifting in low-seam coal are presented.

INTRODUCTION

Underground miners who work in low-seam coal mines (≤48-in roof height) often lift heavy materials in severely restricted work postures. The two postures most often used during MMH activities in low-seam mines are stooped and kneeling (*1*).[2] Each of these postures cause considerable stress to the spine, and may help to explain the high incidence of low-back pain (LBP) in the mining industry. For example, the stooped posture (which causes the spine to be severely flexed) has been shown to substantially increase the pressure on the shock-absorbing disks of the spine (*2*). This increased pressure will cause the disk to deform and may cause the back of the disk to protrude and impinge upon the spinal nerves, which will result in LBP (*3*). The kneeling posture, on the other hand, causes the miner to use a twisting motion of the trunk to accomplish a lift (owing to the limited mobility afforded by working on one's knees). The torsional load experienced by the spine when the trunk is twisted has recently become much more recognized as a significant mode of injury to the low-back (i.e., lumbar) region of the spine (*4*). Therefore, the postures most often used to lift materials in the low-coal environment cause the miner to perform what are generally regarded as the two worst actions in terms of causing LBP: bending and twisting (*3-5*).

Many researchers have attempted to develop lifting limits for materials handling in unrestricted work postures (*6-8*). However, very little research has been performed that has studied the problems associated with lifting materials in restricted postures (*9*). Traditionally, three approaches have been used to set lifting limits: the physiological approach, the biomechanical approach, and the psychological approach (*1, 10*).

The physiological approach uses measurements such as heart rate or oxygen consumption as indexes of the heaviness of work performed, while the biomechanical approach attempts to calculate the compressive and shear forces on the disks of the lumbar spine. However, using either of these two approaches alone may be misleading because both physiological and biomechanical stresses are involved in all lifting tasks. The psychophysical approach uses subjective estimates of acceptable weight-lifting burdens in an effort to integrate the physiological and biomechanical stresses inherent in a lifting task (*10*).

In the Bureau's development of lifting recommendations for low-seam coal mines, a combination of methods of establishing acceptable lifting limits has been used. This paper presents the results of Bureau research examining (a) maximum acceptable weights of lift (MAWL) in restricted lifting postures, (b) back strength capabilities of underground miners, and (c) the physiological stresses of lifting in restricted postures (especially with regard to prevention of muscular fatigue).

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[2] Italic numbers in parentheses refer items in the list of references at the end of this paper.

MAXIMUM ACCEPTABLE WEIGHTS OF LIFT IN STOOPED AND KNEELING POSTURES

Eleven healthy male underground miners [mean age (*M*) = 36 yr, ±8 yr standard deviation (SD)] participated in a study to examine the effects of posture on lifting capacity. Subjects were volunteers from low-seam coal mines and were experienced with handling materials in restricted work postures. Each subject was asked to adjust the weight in a 20- by 13- by 7-in lifting box according to his estimate of lifting capacity for each posture (stooped or kneeling). The lifting tasks were performed under an adjustable-height mine simulator that restricted the subject's posture. The height of the simulator was set at 48 in for this study. Figure 1 is a schematic of a subject performing the lifting task in the stooped posture.

Lifting instructions were given to the subject before the experiment started. In this study, the subjects were told to adjust the weight in the box so the load could be handled for a 20-min period (the actual lifting period) and to assume that this 20 min of lifting would have to be performed four times during a workday. The subject lifted the box at a frequency of 10 lifts/min for two 20-min periods in each posture. One period started with a heavy box, weighing approximately 95 lb, and the other with a light box, weighing approximately 15 lb, to control for bias due to initial starting weight of the box. A 10-min rest break was provided between tests so that subjects could rest and/or attend to personal needs. The average subjectively determined weight chosen for the two test conditions in a posture was taken as the maximum acceptable weight of lift (MAWL) for that posture. Two additional 10-min lifting periods were included to observe the physiological responses of lifting a 50-lb box in each posture.

The primary dependent measures for the psychophysical lifting study were the MAWL for the kneeling and stooped postures. Secondary dependent measures included heart rate (HR), oxygen utilization (VO_2), and ventilation volume (V_E). Heart rate was obtained during the last 10 s of every minute using a Beckman Dynograph Recorder,[3] model 511-A. The average heart rate for each condition was taken as the average of the final 15 values obtained. $\dot{V}O_2$ and V_E values were obtained approximately every 30 s during the final 5 min of lifting using a Beckman metabolic measurement cart. The data were averaged by the number of values acquired during this 5-min period.

During the tests of lifting capacity, integrated electromyography (EMG) was obtained from the same eight trunk muscles in five of the subjects. The muscles studied were the right and left erector spinae, latissimus dorsi, external oblique, and rectus abdominis (see figure 2). These data were obtained during the first and last minutes of the lifting period. The purpose of this data collection was to examine the function of trunk muscles during lifting in stooped and kneeling postures. The integrated EMG data were analyzed as a percentage of the maximum EMG activity for each specific muscle.

The results of data for the tests of lifting capacity in kneeling and stooped postures (along with the associated metabolic demands) were analyzed using Student's t-test. Integrated EMG data obtained during the tests of lifting capacity were analyzed using a 2 by 2 by 3 (posture X beginning-ending of lifting period X initial box weight) analysis of variance (ANOVA). Critical alpha levels were 0.05 in all cases.

[3] Reference to specific products does not imply endorsement by the Bureau of Mines.

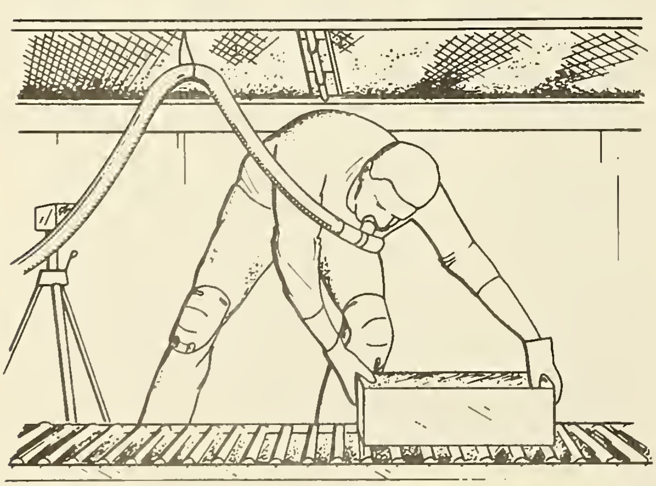

Figure 1.—Schematic of subject performing lifting capacity test in stooped posture.

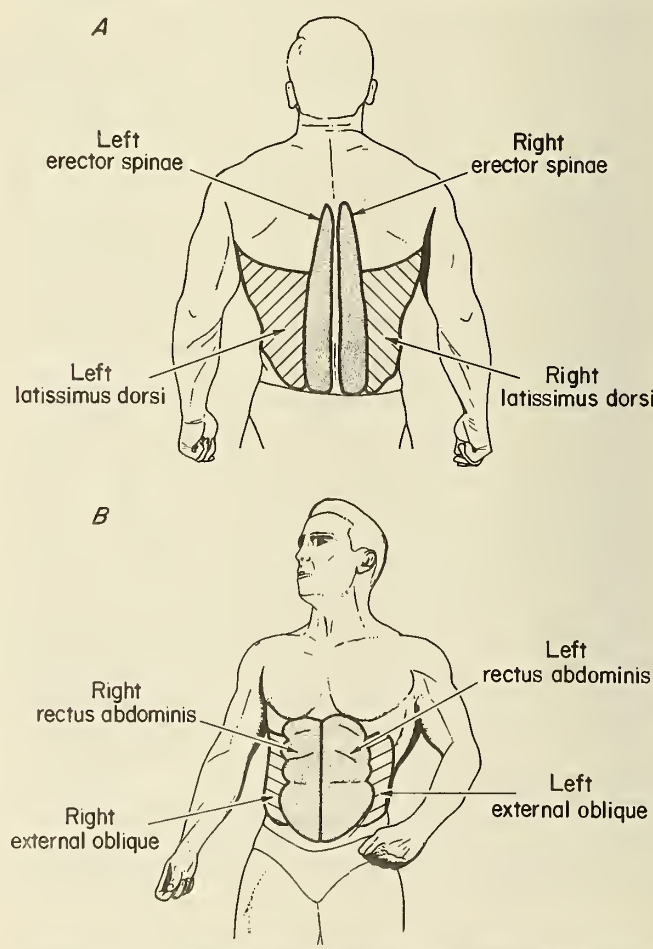

Figure 2.—Trunk muscles studied by means of electromyography.

RESULTS

The results of the psychophysically determined MAWL tests are presented in table 1. As demonstrated in this table, the kneeling MAWL for the 11 subjects was significantly lower than the stooped MAWL [probability (p) <0.01]. However, despite the fact that significantly less weight was lifted in this posture, the physiological demands of lifting in this posture were significantly higher than the stooped posture for HR (p <0.01) and V_E (p <0.05).

Table 1.—Results of maximum acceptable weight of lift (MAWL) test for all underground miners (N=11)

	Stooped		Kneeling		p, probability
	Rate	SD	Rate	SD	
MAWL ....lb..	66.2	±9.5	58.5	±11.7	<0.01
Heart rate (HR)......beats/min..	122	±12	136	±14	<.01
Oxygen utilization					
(VO_2) ....(mL/kg)/min..	14.6	±3.0	16.0	±4.5	[1].057
Ventilation volume (V_E) ...L/min..	31.6	±4.8	34.7	±8.0	<.05
Respiratory exchange ratio (R) ...	.82	±.09	.83	±.07	[1].843

SD Standard deviation. [1] Not significant.

The data for determining the metabolic cost of lifting a 50-lb box are presented in table 2. The data presented in this table clearly demonstrate the greater metabolic demands of lifting in the kneeling posture. HR (p <0.001), VO_2 (p <0.001), V_E (p <0.001), and respiratory exchange ratio (R) (p <0.05) were all significantly greater in the kneeling posture compared to the stooped position.

Table 2.—Metabolic cost of lifting a 50-lb box for underground miners (N=11)

	Stooped		Kneeling		p, probability
	Rate	SD	Rate	SD	
Heart rate (HR)......beats/min..	116	±11	129	±16	<0.01
Oxygen utilization					
VO_2)............(mL/kg)/min..	12.6	±2.7	14.9	±2.7	<.001
Ventilation volume (V_E) ...L/min..	25.5	±5.5	30.9	±5.9	<.001
Respiratory exchange ratio (R) ...	.79	±.08	.82	±.09	<.05

SD Standard deviation.

The four back muscles studied demonstrated significantly more integrated EMG activity in the kneeling posture as opposed to lifting while stooped. The ANOVA (using Fisher's statistic, F) for mean integrated EMG showed significant main effects due to posture for the right latissimus dorsi (F = 37.889, p <0.001), left latissimus dorsi (F = 8.189, p <0.01), right erector spinae (F = 30.522, p <0.001), and left erector spinae (F = 6.736, p < 0.05). Similarly, the ANOVA for maximum integrated EMG demonstrated significant main effects due to posture for the right latissimus dorsi (F = 56.549, p <0.001), left latissimus dorsi (F = 11.739, p <0.01), right erector spinae (F = 35.992, p <0.001), and left erector spinae (F = 26.673, p <0.001).

Table 3 shows the average values (for five subjects) of the maximum integrated EMG for all four back muscles during lifting in both stooped and kneeling postures.

Table 3.—Percentage of maximum electromyography (EMG) during lifting tasks in stooped and kneeling postures (N = 5)

	Stooped	Kneeling	p, probability
Latissimus dorsi:			
Right	24	71	<0.001
Left	23	53	<.005
Erector spinae:			
Right	13	53	<.001
Left	16	52	<.001

Similar results were obtained in the analysis of mean integrated EMG. None of the abdominal muscles studied (i.e., left and right external obliques and rectus abdominus) were significantly affected by posture (p >0.05). There were no significant effects on any muscle due to, initial box weight (p >0.05) or due to sampling the EMG's at the beginning or the end of the lifting period (p >0.05). Furthermore, there were no signficant interactions observed between any of the independent variables (p >0.05).

EFFECTS OF POSTURE ON LIFTING CAPACITY

Results of the psychophysical tests of lifting capacity demonstrated that the lifting capacity of underground miners is significantly lower in the kneeling posture than in the stooped position. This difference is due primarily to the decrease in muscle mass that can be utilized when lifting in the kneeling position. These results indicate that there is a significant biomechanical disadvantage to lifting in the kneeling position as compared to the stooped-over posture. It should be noted that this biomechanical handicap (i.e., decreased muscle mass) was also evident in the back strength investigation reported below.

The results of analyses of integrated EMG data collected during the lifting capacity sessions indicate that the loading on the back due to contraction of the back muscles is also quite different in these two restricted work postures. All four back muscles studied (i.e., right and left erector spinae and latissimus dorsi) demonstrated significantly higher muscular activity when subjects were lifting in the kneeling posture.

The greater the contraction of the back muscles, the greater the compressive load that is experienced by the intervertebral (IV) disks of the spinal column. Therefore, an increased load is experienced by the IV disks and other structures of the vertebral column when lifting is performed in the kneeling posture. This will ultimately lead to increased wear and tear on these structures, which may lead to an increased incidence of back pain. Furthermore, these results indicate that the back muscles are working at a high intensity of a reduced muscular capacity when lifting in the kneeling posture. This would indicate that the back muscles will fatigue more quickly when performing materials-handling tasks in the kneeling posture. More rapid fatigue of the musculature of the back is another potential factor that may predispose the worker to experiencing a back injury.

It is interesting to note that physiological responses to lifting in the kneeling posture were significantly greater than in the stooped posture, despite the fact that less weight was lifted when kneeling. The increased metabolic demands of lifting in this posture is another factor that may limit lifting capacity in the kneeling position. One reason for the increased metabolic demands of lifting in this posture is the increased back muscle activity described earlier. An increase in muscular contraction increases the demand for oxygen in the working muscle, which in turn increases both heart rate and respiration in order to supply the necessary oxygen. The increased metabolic cost of lifting when kneeling is another indication that onset of fatigue will be more rapid when working in this posture. It should be borne in mind that physical fatigue also has psychological consequences that often lead to unsafe work practices, which may lead to an increase in musculoskeletal injuries.

Previous research has indicated that an acceptable weight of lift be defined as one that can be lifted by 90 pct

of an industrial population, as determined in a psychophysical study. Establishing an acceptable weight-lifting burden according to this criterion has been shown to significantly reduce the cost and incidence of low-back pain.

Based on the data on lifting capacity of underground miners in the stooped and kneeling postures presented in this paper, the acceptable weight of lift for the stooped posture is 54.0 lb, while the acceptable weight of lift for the kneeling posture is 43.5 lb. These values are based on a lifting frequency of 10 lifts/min and apply to lifting compact loads. This result is of some interest because of the fact that one of the most commonly handled materials in underground coal mines is the 50-lb rock-dust bag.

Based on the acceptable weight-lifting burdens described, 50 lb is an acceptable weight of lift for the stooped posture; however, it exceeds the recommended maximum for lifting in the kneeling posture. This outcome suggests that redesign of certain materials should be given serious consideration. For instance, rock dust might be packaged in 40-lb instead of 50-lb bags in order to conform to the acceptable weight-lifting burden recommended for the kneeling posture, especially in mines where a great deal of lifting is performed in this posture. Redesign of other commonly handled supplies should also be examined. Such ergonomic redesign of supplies may have a significant impact on the costs associated with back injuries in low-coal mines.

BACK STRENGTH OF UNDERGROUND MINERS IN STANDING AND KNEELING POSTURES

METHOD

Twelve coal miner subjects (M = 37 yr, ±8 yr SD) participated in tests of back strength in both standing and kneeling postures. Back strength was measured using a CYBEX Isokinetic Dynamometer (LUMEX, Inc.). A total of 12 conditions were studied in this experiment: six kneeling and six standing. In each posture, three back strength measurements were taken using an isometric contraction (22.5°, 45.0°, and 67.5° from vertical) and three measurements were made using a dynamic contraction (30°/s, 60°/s, and 90°/s). Figure 3 is a schematic of the device used to measure back strength during tests in both standing and kneeling postures. The subject was secured by a pelvic stabilization strap in each posture. All back strength test conditions were conducted in a counterbalanced order.

The maximum voluntary contraction (MVC) for each test condition was obtained using a test-retest procedure whereby peak torque measurements (foot-pounds) of two maximal exertions were required to be within 10 pct of one another (*11*). The higher of these two values was taken as the MVC for that test condition. Two minutes rest was given

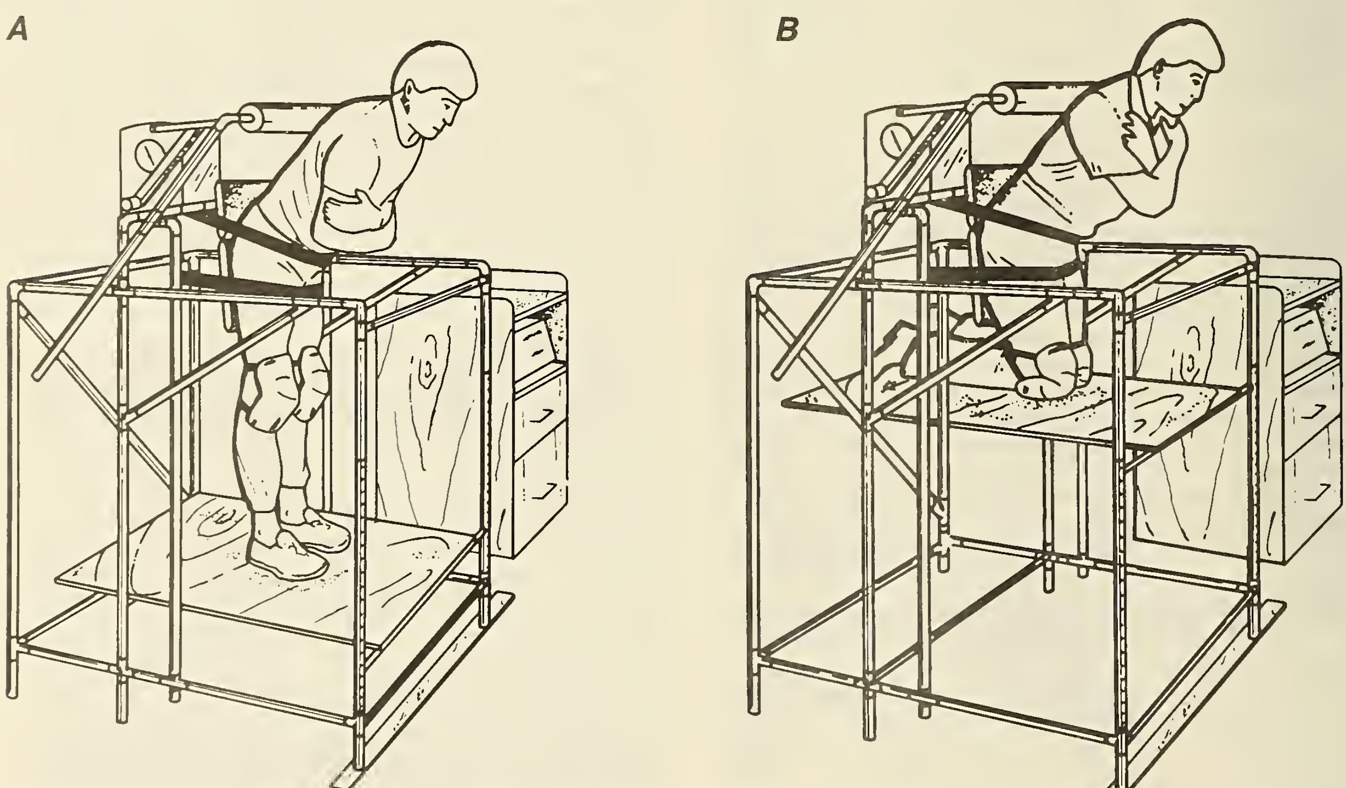

Figure 3.—Schematic of subject performing back strength exertions in (*A*) standing, and (*B*) kneeling postures.

between exertions, and consistent verbal encouragement was given in order to facilitate maximal exertions from the participants.

During the back strength exertions, integrated EMG data were collected from eight trunk muscles in five of the subjects studied. The muscles studied were both right and left erector spinae, latissimums dorsi, external obliques, and rectus abdominis. Resting EMG values for all eight muscles were obtained in both postures (standing and kneeling) at three trunk angles; 22.5°, 45.0°, 67.5° from vertical. The EMG data for each exertion were expressed as a percentage of the maximum integrated EMG obtained over all tests for each specific muscle.

The data collected on peak torque achieved during the static back strength tests were analyzed in a 2 by 3 (posture X trunk angle) ANOVA on repeated measures design. Data for the dynamic strength tests were also analyzed in a 2 by 3 (posture X speed of contraction) ANOVA on repeated measures design. The integrated EMG data of each trunk muscle obtained during the back strength testing was analyzed using a 2 by 3 by 4 (posture X trunk angle X velocity) ANOVA. The level of significance was 0.05 in all cases.

RESULTS

Posture did not significantly affect peak torque for either static back strength ($F_{1,4}$ = 2.186, p = 0.213) or dynamic back strength ($F_{1,4}$ = 0.535, p = 0.505). Trunk angle demonstrated a significant main effect on peak torque production for the static exertions ($F_{2,8}$ = 11.337, p <0.05). However, speed of contraction did not demonstrate significance for the dynamic back strength tests ($F_{2,8}$ = 1.35, p = 0.310). Neither the interaction between posture and trunk angle in the static exertions ($F_{2,8}$ = 1.295, p = 0.319), nor the interaction of posture and speed of contraction in the dynamic test ($F_{2,8}$ = 0.967, p = 0.381) were significant.

The back strength data are presented in figure 4. The analysis of the static back strength of the 12 subjects demonstrated a significant main effect on peak torque due to trunk angle ($F_{2,22}$ = 34.797, p <0.001); however, posture did not significantly affect peak torque production in the static exertions ($F_{1,11}$ = 3.414, p = 0.092).

Posture did have a significant main effect on peak torque produced in the dynamic exertions ($F_{1,11}$ = 8.797, p <0.05), as did the speed of the dynamic contraction ($F_{2,22}$ = 13.469, p <0.001). The interaction between variables was not significant in either the static exertions, ($F_{2,22}$ = 0.326, p = 0.725), or the dynamic exertions ($F_{2,22}$ = 0.042, p = 0.959).

Tables 4 and 5 present summaries of the ANOVA results for maximum and mean EMG data collected during the back strength exertions, respectively. Posture was found to affect only the EMG activity of the left latissimus dorsi muscle, which was higher in the kneeling posture than the standing posture. However, it should be noted that all four back muscles studied had generally greater EMG activity in the kneeling posture than when standing. The failure of this trend to achieve statistical significance is probably the result of the limited EMG sample size. In the analysis of both maximum and mean integrated EMG activity, the latissimus dorsi muscles were more affected by the velocity of contraction, while the erector spinae muscles were more significantly affected by the angle of trunk flexion during the back strength exertion.

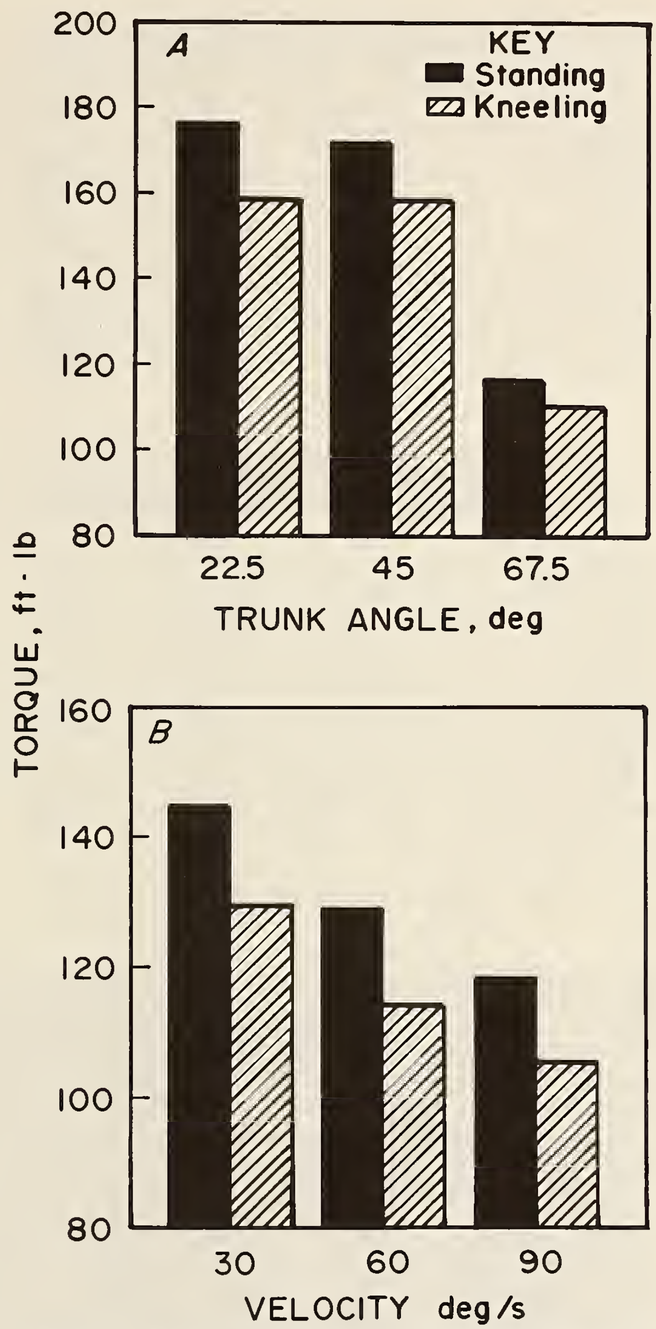

Figure 4.—Peak torque achieved by underground miners during (*A*) static, and (*B*) dynamic back strength tests.

Figure 5 presents averaged data describing the relative myoelectric activity of the erector spinae and latissimus dorsi muscles and the relative torque achieved, expressed as a function of velocity of contraction. This figure demonstrates that while the function of the back muscles studied are similar in static exertions whether standing or kneeling, that there are significant differences in trunk muscle function in the dynamic contractions. For instance, while the relative activity of the latissimus dorsi declines consistently in the standing exertions as the speed of contraction increases, in the kneeling posture one can see an increase in latissimus activity at the faster speeds. Furthermore, the erector spinae muscles exhibit a dramatic increase

Table 4.—Summary of ANOVA results for maximum integrated electromyography (EMG) and torque during experimental conditions, probability (p)

	Posture	Trunk angle	Velocity
Latissimus dorsi:			
Right	0.20	0.19	<0.001
Left	<.05	.40	<.001
Erector spinae:			
Right	.08	<.001	.36
Left	.11	<.001	.41
External oblique:			
Right	.36	.09	<.05
Left	.06	.10	.13
Rectus abdominis:			
Right	.73	.49	.64
Left	.26	.36	.93
Normalized torque	.25	<.001	<.001

Table 5.—Summary of ANOVA results for mean integrated electromyography (EMG) and torque during experimental conditions, probability (p)

	Posture	Trunk angle	Velocity
Latissimus dorsi:			
Right	0.21	<0.01	<0.05
Left	<.05	<.05	<.05
Erector spinae:			
Right	.16	<.001	.07
Left	.13	<.001	.27
External oblique:			
Right	.32	<.01	.54
Left	.14	<.001	.59
Rectus abdominis:			
Right	.65	.12	.83
Left	.26	<.05	.98
Normalized torque	.20	<.001	<.001

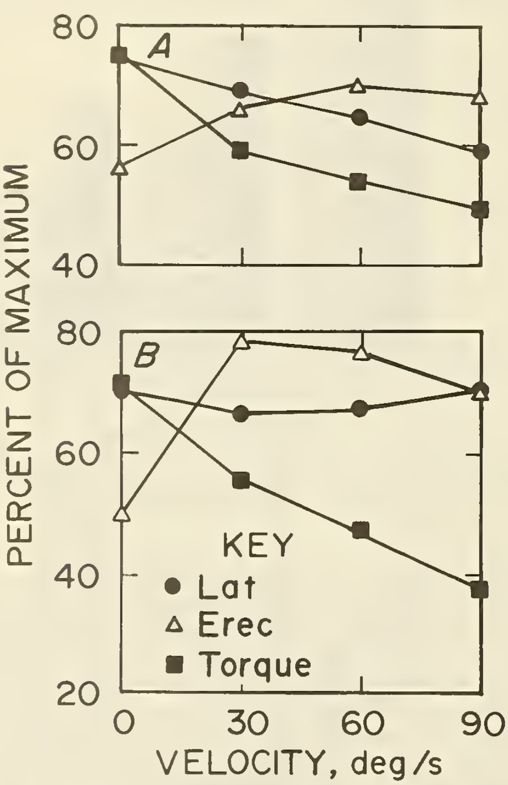

Figure 5.—Mean latissimus dorsi (Lat.) and erector spinae (Erec.) EMG, and torque production (percent of maximum torque achieved) averaged over experimental angles and expressed as a function of velocity in (*A*) standing and (*B*) kneeling back exertions.

in activity between the static condition and the 30°/s contraction when kneeling; this sudden increase in activity is not seen in the standing posture. However, despite the higher EMG acitivity of the back muscles in the kneeling posture, it can be seen that decrease in relative torque as a function of increasing speed of contraction is greater in this posture than standing.

EFFECTS OF POSTURE ON BACK STRENGTH

Results of the back strength testing of 12 subjects indicate that there is a significant reduction in dynamic peak torque production when back strength is measured in the kneeling posture as opposed to standing. Static back strength was also generally lower in the kneeling position; however, the difference did not achieve statistical significance. The failure to achieve statistical significance of posture effects in the static tests is probably due to the limited sample tested thus far.

Nevertheless, it should be noted that lifting tasks in underground mines (as in most industrial situations) are primarily performed dynamically, and the fact that underground miners exhibited less dynamic strength when kneeling indicates that miners who must lift in this posture are stressing their back musculature to a greater percentage of the muscles' total capacity than if the same lifting task were performed standing. Furthermore, as back strength correlates well with lifting capacity, a lower lifting capacity would be expected when handling materials in the kneeling position. This finding helps to explain the decreased lifting capacity of underground miners in the kneeling posture as described previously.

Both trunk angle and velocity of contraction were demonstrated to have significant main effects on peak torque achieved during static and dynamic back strength exertions, respectively. These findings are in agreement with the results of previous studies that have examined the effects of these variables on back strength (*12-13*). The implication of this finding in the current investigation is to demonstrate that, although a decrease in torque is attributable to measurement of back strength in the kneeling posture, both trunk angle and velocity of contraction affect peak torque achieved in a similar manner, whether standing or kneeling.

Both mean and maximum integrated EMG data were collected from five of the subjects who performed the back strength tests. The results of the analysis of both mean and maximum EMG's indicate that posture significantly affected only the activity of the left latissimus dorsi muscle, which was more active in the kneeling posture than when standing. However, it should be duly mentioned that all four back muscles examined were consistently more active in the kneeling posture than when standing. The failure to achieve statistical significance of back muscle function because of posture is probably a result of the limited EMG sample examined.

Other findings from the back strength EMG analysis demonstrated that the erector spinae function was significantly more affected by the angle of the trunk during the exertion, while the latissimus dorsi muscles were affected more by the velocity of the contraction. These findings are in agreement with results from other researchers, and demonstrate that the effects of trunk angle and velocity of contraction on back muscle function are not affected by the posture assumed during the exertion.

The results described reflect some of the effects that body posture has on the biomechanics of the muscle groups that may take part in a lifting activity. It is apparent that there is a reduced muscle mass employed during back exertions in the kneeling posture as opposed to standing. This indicates that during the measurement of back strength in the standing posture, there is a contribution of muscular forces from muscles other than those of the low-back region, presumably the muscles of the posterior aspect of the legs.

The implication of this finding is that, in order to truly determine the function of the low-back muscles, one must adequately isolate this muscle group. Differences in back strength measurements taken in the standing posture, in other words, may not accurately reflect true differences in force production of the low-back musculature, but may instead reflect differences in the strength of, say, the hamstring group. This is not to say that measurement of back strength in the standing position is not valuable; in most lifting situations, a worker will be able to use the additional muscular force afforded by the legs. However, if one assumes that standing measurements of back strength are indicative solely of forces produced by the low-back muscles, incorrect conclusions may be drawn.

The author does not contend that the assessment of back strength in the kneeling posture affords the best method of isolating forces of low-back muscles. Further research is necessary before the optimal method of assessing low-back strength is identified.

LABORATORY ASSESSMENT OF METABOLIC DEMANDS ASSOCIATED WITH SELECTED UNDERGROUND MATERIALS-HANDLING TASKS

Increased metabolic demand is an indication that the onset of physical fatigue will be more rapid. Because physical fatigue has psychological consequences that often lead to unsafe work practices and associated musculoskeletal injuries, laboratory assessments of metabolic demands of three materials-handling tasks were made.

METHOD

Nine experienced low-seam coal miners were used as test subjects. Each subject performed three materials-handling tasks (i.e., crib building, brattice building, and moving rock-dust bags). In an attempt to replicate the conditions in the mine as closely as possible, an adjustable-height mine simulator was constructed and used for testing. The simulator was constructed of sections of 2- by 4-in framing that bolted together to provide a 12- by 16-ft cage with a roof that could be varied in height (see figures 6–8). The miners were instructed to complete the following tasks.

Crib Building.—The crib building task involved having the miner move the necessary crib blocks (rough-sawn 6- by 6-in blocks, approximately 3.5 ft long, weighing approximately 14–16 lb) from one side of the simulator to the other and then proceed with building the crib. The blocks were placed in tiers in alternating directions until the necessary height was reached and then tightening wedges were inserted to complete the task.

Figure 6.—Underground mining test subject building a roof-support cribbing during which metabolic data are gathered (note mouthpiece, headgear, and flexibile tubing for collection of expired gases).

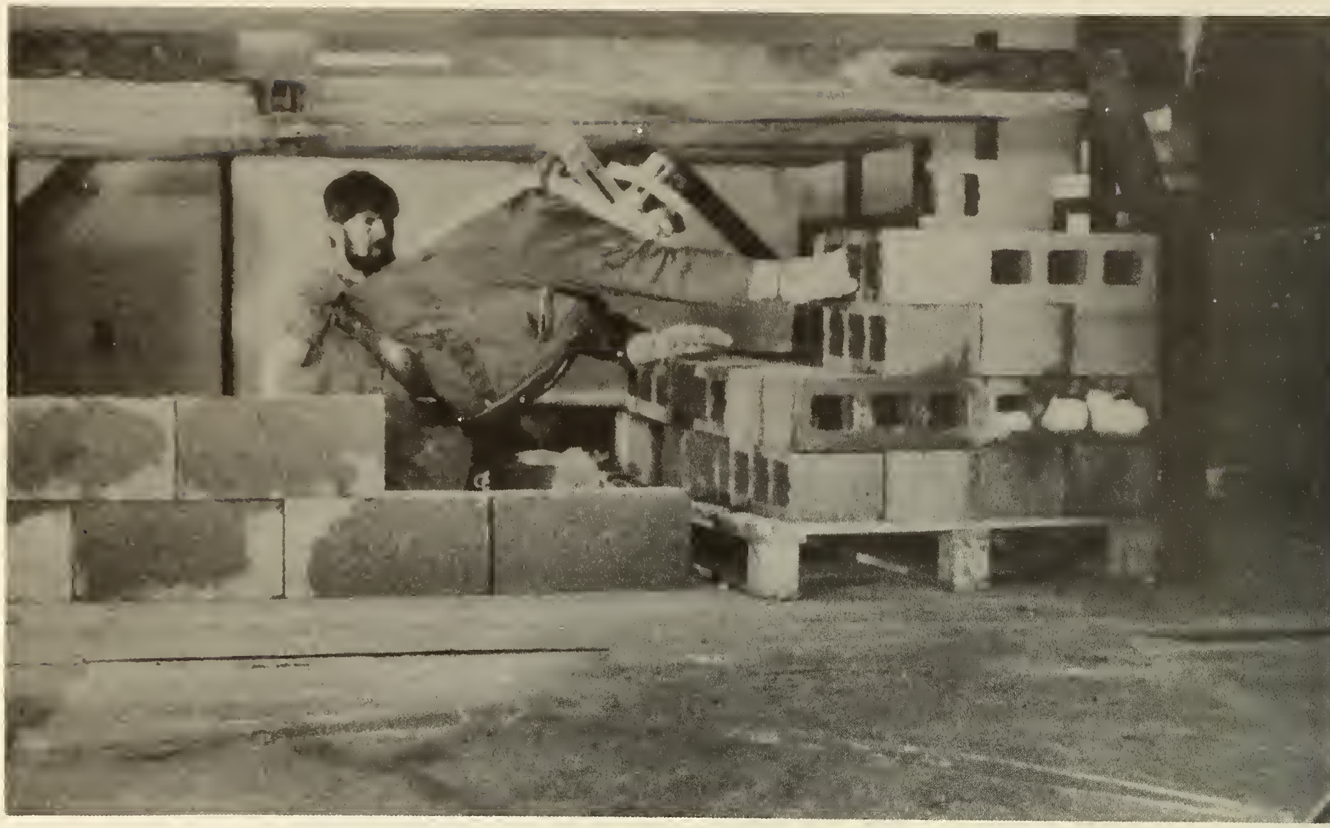

Figure 7.—Test subject building a brattice (ventilation stopping).

Figure 8.—Miner lifting 50-lb rock-dust bags from a supply pile to the opposite side of the mine simulator.

Brattice Building.—The requirements for this task were to move the necessary number of standard cinder blocks (approximately 22 lb each) from one side of the simulator to the other and to build a stopping five blocks high. Each miner used the approach of moving several blocks, building, and repeating the process until the task was completed.

Moving Rock-Dust Bags.—This task was designed to simulate removing a load of rock-dust bags from a scoop. It involved moving 22 standard (50-lb) rock-dust bags from a pile on one side of the simulator to a pile on the other side. Each bag was moved between 6 and 8 ft.

Each miner was outfitted with a welder-type headset, one-way respiratory valve, mouthpiece, and nose clip (see figures 6–8). The expiratory side of the respiratory valve was attached to a Beckman metabolic measurement cart via a flexible respiratory tubing. This flexible tubing was necessary to allow the subjects to perform the specified task and have the measurement cart located outside of the simulator. The cart was calibrated for volume, O_2, and CO_2 prior to each testing session. The cart produced printouts at 30-s intervals for (a) volume expired, (b) VO_2 in L/min and (mL/kg)/min, and (c) respiratory exchange ratios.

The preparatory phase for each session involved fitting the subject with the headgear and respiratory valves, and allowing the subject to rest in a kneeling position in the simulator until reasonable baseline values (VO_2 <0.50 L/min) were being recorded. The subject then performed the task while data were recorded continuously. The duration of the tasks was such that five to eight metabolic recordings were made during the work period. Recovery samples were recorded continuously from the end of the task until the subjects were back to near baseline values (VO_2 = 0.50 L/min). The recovery phase typically lasted 3 to 5 min.

RESULTS AND DISCUSSION

The metabolic data clearly indicate that moving rock-dust bags was the most physiologically demanding of the materials-handling tasks evaluated. Figure 9 presents a comparison of the oxygen uptake, in liters per minute, for all three tasks. Inspection of this figure reveals a much greater rate of rise of oxygen uptake for moving rock-dust bags as compared with oxygen uptake for the other tasks. The increased slope is an additional indication of the severity of the task. The metabolic demands of cribbing (5.20 METS[4]) and building a ventilation stopping (4.95 METS) were quite similar and notably lower than the maximum recorded value of 6.25 METS for moving rock-dust bags.

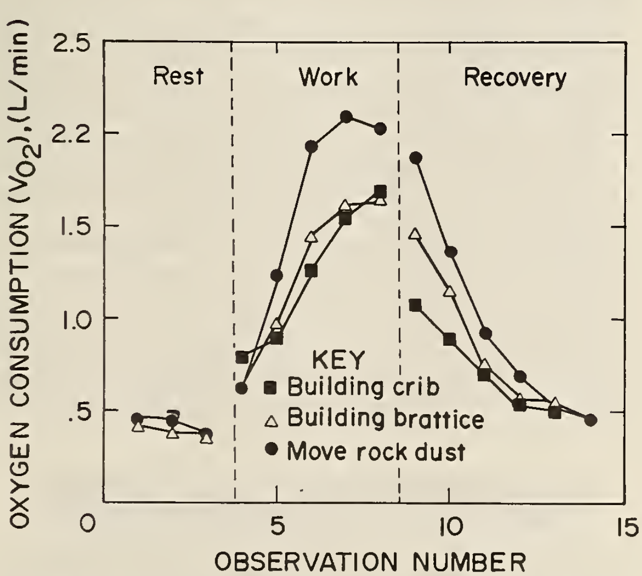

Figure 9.—Comparison of oxygen consumption rates during performance of three materials-handling tasks.

The data presented in this paper are very comprable to results obtained by Ayoub (*14*), who measured the metabolic demands of miners performing various jobs in a low-seam underground mine. The tasks studied in that research were typically of a relatively short-duration (3 to 5 min in length), and required oxygen uptake values ranging from approximately 1.00 L/min (for roof bolting) to roughly 2.25 L/min (for setting jacks, bending bolts, and moving materials). Other metabolic demands for mining tasks reported by Ayoub included shoveling (1.86 L/min), helping (1.45 L/min), and timbering (1.20 L/min). In comparison with the data from Ayoub (*14*), the data for building a crib or a stopping presented in this paper might be considered average in terms of energy expenditure for mining jobs, while moving rock-dust bags would require a greater than average metabolic cost as compared to most mining tasks.

As noted, the most difficult task identified in the laboratory assessment was that of moving rock-dust bags. From a physiological standpoint, consideration should be given to redesigning this task. Three possible approaches might be considered: (a) the weight of the individual bags could be reduced from the present 50 lb to 40 lb; (b) a training program could be developed to reduce the rate at which the present 50-lb bags are handled; and (c) methods of delivering rock dust mechanically should be investigated. If none of these alternatives are viable, an effort should be made to introduce frequent rest pauses during the unloading of bags of rock dust.

The crib and brattice building tasks were less physiologically demanding than moving rock dust. It is important to note, however, that the intensity required to do either of these "easier" tasks could not be sustained for a major segment of a workday. Fortunately, the sporadic nature of materials-handling tasks in underground mines does not require that any of these tasks be performed for extended periods of time.

RECOMMENDED WORK-REST INTERVALS FOR MINING TASKS

Knowledge of the energy expenditure necessary for specific mining tasks is valuable in calculating recommended work-rest intervals that should be followed in order to prevent excessive muscular fatigue. The American Industrial Hygiene Association (*16*) endorses the following formula in establishing work-rest cycles:

$$RT\ pct = [(W - 1.5/4) - 1] \times 100,$$

where RT pct = rest time as a percentage of the time of work,

and W = energy expenditure during work in terms of kilocalories expended per minute.

[4] MET (metabolic equivalent) is the amount of oxygen required per minute by the body under resting conditions. It is equal to 3.5 mL of oxygen consumed per kilogram body weight per minute.

Because an oxygen consumption rate of 1 L/min is equivalent to 5.05 kcal expended per minute, the data presented in this section can be used to calculate the work-rest intervals. For moving rock-dust bags (at a frequency of 12 to 15 per minute) the recommended rest interval would be 120 pct of the time of work. This would mean that if rock-dust bags were moved at a rate of 12 to 15 per minute for a 5-min period of time, the worker should take a 6-min rest break in order for the muscles to recover from the activity. This rest break would allow heart rate and breathing to return to normal, as well as allowing the metabolic end-products of muscular exertion (that lead to muscular fatigue) to be dissipated. Crib building would require a rest break equivalent to 75 pct of the time of work according to the American Industrial Hygiene Association formula, and building a ventilation stopping would require a rest break equivalent to 70 pct of the time of work. These results and the results of studies of energy expenditures during mining tasks from previous authors provide the basis for work-rest intervals shown in table 6.

Table 6.—Recommended work-rest intervals for several underground mining tasks

	Energy expenditure, kcal/min	Rest interval, pct of work time
Moving rock dust bags (12–15 bags/min)	10.25	120
Shoveling	9.28	95
Building a crib	8.48	75
Building a stopping	8.28	70
Helping (miner helper and roof bolt helper	7.15	41
Timbering	6.00	13

PRELIMINARY RECOMMENDATIONS FOR LIFTING IN LOW-SEAM MINES

TRADITIONAL LIFTING RECOMMENDATIONS

The following traditional lifting recommendations are provided for performance of materials-handling tasks in low-seam coal mines.

1. *Use a mechanical assist whenever possible.*—It is obvious that elimination of a manual lifting task by using a mechnical device is the preferred method of handling materials, and that eliminating the lifting task will reduce the number of back injuries due to materials handling. The development of new materials-handling devices is certainly a need in low-coal mines, and mining personnel (both the miners and mine management) should be encouraged to think of ways that physically demanding jobs might be redesigned by using a mechanical-assist device.

2. *Implement systems approach to supplies handling.*—Supply-handling systems in underground coal mines should be analyzed in order to reduce the number of times that materials are handled. For instance, it has been demonstrated that it is possible to keep materials unitized on pallets until the supplies reach an underground storage location, thereby eliminating all manual handling of materials up to this point. However, many mines do not use such a system; instead, palletized loads are broken on the surface and the materials are then loaded manually onto supply cars. Every effort should be made to keep supplies palletized until they absolutely must be used on an individual basis.

3. *Use a smooth lifting motion to accomplish a lift.*—A great deal of research has indicated that sudden or unexpected movements are responsible for a large number of back injuries. The sudden load experienced by a worker's back in this situation is often two to three times as great as when the load is expected. Related to this concept is the recommendation that if an object is stuck underneath other materials, do not attempt to lift it without first removing the debris on top of it. Two problems can be caused by attempting to lift a stuck object. First, the object may not move when expected to, which causes a very high load to be experienced by the lower back; secondly, the object may pull free unexpectedly, which will also place the low back under extremely high stress.

4. *Keep the load as close to the body as possible.*—Biomechanical studies on the loading of the low back have made it clear that the further the load is from the spine, the greater the stress to the low back. Therefore, it is important to keep the load close. While the stooped posture limits how close the load can be from the body, it is still much better to handle the material with the arms hanging straight down than having to extend them out in front of the body when handling a load in the stooped position.

5. *Avoid excessive twisting of the trunk.*—Many researchers are of the opinion that the worst action to perform when lifting is twisting. Twisting puts a severe strain on the fibers of the intervertebral disk, and may actually cause some of these fibers to break, which will severely weaken the disk. Furthermore, it is the opinion of some researchers that injuries to the disk that are caused by twisting are much less likely to heal than injuries to the disk caused by simple bending. Therefore, it is important to position the body so that a minimum of twisting is required to perform a lifting task.

6. *If an object is too heavy to lift by yourself, get help.*—Many back injuries occur because of a person trying to lift more weight than one individual can safely lift. It is important to take the time to find someone to assist with the lifting task.

7. *Become more physically fit.*—Being a miner is one of the most physically demanding jobs imaginable. This means that miners should be more fit than most other workers in order to meet the physical requirements of the job. Unfortunately, many studies have shown just the opposite to be the case. Many back injuries could probably be avoided by strengthening back and abdominal muscles and making them more flexible.

8. *Take care of your back at home.*—Attention to back care should not stop at the portal. Many back injuries may be caused by everyday activities such as driving with the seat of your car too far back, doing yard work, or sleeping on a mattress that is too soft. There are also two-person jobs at home, and it is important that the safe lifting techniques employed at work be transferred to the home environment.

RECOMMENDATIONS BASED ON BUREAU ERGONOMICS LABORATORY RESEARCH

The studies described in this paper have been performed by the Bureau to determine the specific lifting stresses encountered by low-coal miners. These studies have included

tests of psychophysically determined lifting capacity, assessment of the back strength of the underground mining population, the relationship of back strength to lifting capacity in restricted work postures, and the metabolic demands of materials-handling tasks in kneeling and stooped postures. It should be noted that the following recommendations deal primarily with compact loads (such as rock-dust bags, cribbing block, and concrete blocks) that are handled repetitively by underground miners. Future research will focus on other aspects of underground materials handling. It should be recognized that the sample size on which these recommendations are based is still somewhat limited. However, many statistically significant findings have already been demonstrated through in-house Bureau research with regard to acceptable weights of lift in restricted work postures and the physiological costs of lifting activities in these postures. The following recommendations are based upon the results of this research.

1. *Maximum acceptable weights of lift (MAWL) for kneeling and stooped postures.*—The results of the psychophysical tests of lifting capacity of underground coal miners have demonstrated that the acceptable weight of lift in the kneeling posture is significantly lower than that of the stooped posture ($p < 0.01$). It has been shown that an acceptable weight of lift is defined as one that 90 pct of the working population are able to lift using the psychophysical methodology (*15*). Using this criterion, the MAWL's for underground miners are 54.0 lb in the stooped posture, and 43.5 lb in the kneeling posture.

2. *Heavier weights may be handled more safely in the stooped posture.*—Given a choice of handling a heavy weight (> 50 lb) in the stooped or kneeling positions, it may be better to handle the weight stooped, because of the higher lifting capacity of miners in this posture. The results of the research indicate that the stooped posture may be better, though admittedly not a great deal better, for handling heavier loads as compared to the kneeling posture.

3. *More frequent rest breaks should be taken in the kneeling posture.*—The studies performed at the Bureau's ergonomics laboratory have clearly indicated that increased metabolic demands are required when handling materials in the kneeling posture. In fact, the underground miners tested to date have demonstrated that both heart rate and ventilation volume have been significantly higher in the kneeling posture than stooped ($p < 0.05$), despite the fact that significantly *less* weight was lifted when kneeling ($p < 0.01$). Therefore, in order to prevent the onset of muscular fatigue that may ultimately lead to musculoskeletal injury, more frequent rest breaks may be necessary in the kneeling posture.

4. *Redesign of manually handled materials used in low-coal mines should be considered.*—Bureau research has indicated that in low-coal mines, nearly 60 pct of a worker's time spent in materials-handling activities may be in the kneeling posture (*1*). Because of the lower lifting capacity of miners in this position, consideration should be given to redesign of the loads that must be handled in low-coal mines. For instance, a 50-lb rock-dust bag is an acceptable weight to lift in the stooped posture according to the findings reported. However, this weight is significantly higher than the acceptable weight of lift for the kneeling posture (i.e., 43.5 lb). Therefore, it may be advisable to consider repackaging rock dust into 40-lb bags for low-coal mines that require a great deal of materials handling in the kneeling position. Designing the load to match the psychophysically established acceptable weight of lift has been shown to be beneficial in decreasing both the incidence and severity of back injuries (*15*).

5. *Recommended work-rest cycles for various mining tasks.*—Recommended work-rest intervals for various mining tasks are presented in table 6. These work-rest cycles are based on a formula endorsed by the American Industrial Hygiene Association (*16*). Information on the energy expenditure for the mining tasks included in this table are based on data collected by the Bureau (*14*).

6. *Effects of posture on back strength.*—The analysis of back strengths of miners showed that dynamically measured back strength was significantly lower when kneeling as opposed to standing. A biomechnical analysis performed by the Bureau (not described in this paper) demonstrated that trunk extension was the primary action used to accomplish several underground materials-handling tasks (*17*). Therefore, a great deal of stress is being put on the back extensor muscles during the performance of these tasks at a time when the muscles are at a significant biomechanical disadvantage. Reducing the weight of loads handled in the kneeling posture may help to ease the burden on the stressed back muscles and may help to reduce the incidence of back injuries in this posture.

7. *Sensitivity to working in the stooped posture.*—It became apparent during the tests of lifting capacity that certain individuals were not as tolerant to working in the stooped posture as others. These individuals were generally those who had more incidence of low-back pain. Overweight test subjects also tended to be more sensitive to stooped materials handling. One subject elected not to finish the lifting capacity test in this posture. Therefore, it is suggested that individuals who have experienced significant low-back pain or who are overweight, exercise particular caution when handling materials while stooped. Shorter periods of materials handling in this procedure are indicated for such individuals in order to prevent recurrence of low-back pain.

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ERGONOMIC ANALYSIS OF THE JACKLEG DRILL

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ABSTRACT

Research conducted for the Bureau of Mines by The Ohio State University has indicated that the jackleg drill, commonly used in underground metal-nonmetal mines, was involved with 46 pct of all lost-time handtool-related accidents during the 1978-83 6-yr period. Videotapes of underground operations of jackleg drills have been collected and analyzed to determine the drills' biomechanical forces on the operators.

A detailed task analysis identified that carrying the drill, positioning the drill steel, collaring the hole, and pulling the drill steel out of downward angled holes all contribute severe loadings to the drill operator's lumbar spine. A laboratory experiment was designed to investigate the stresses on the trunk muscles while performing these four tasks under controlled conditions. Preliminary electromyographic (EMG) data are presented.

INTRODUCTION

Handtools have been in use by humans since prehistoric times. They are commonly found in most households and are regularly used in virtually all occupations. Certain industries and occupations require workers to use handtools more often then others, and many times the nature of the task or tool puts these workers at a greater risk of injury than the typical industrial population. Underground mining is just such an industry.

Statistics from the Mine Safety and Health Administration (MSHA), Department of Labor, indicate that from 1980 through 1984 handtools were involved in a total of 8 pct of all the lost-time nonfatal injuries in underground coal mining.[4] In addition, a total of 21 pct of all hand and finger injuries were caused by the use of handtools during the same 5-yr period.[5]

Mining is the brute-force extraction of raw materials from the surrounding rock. Thus, the extraction equipment is very large, quite powerful, and made to be durable. Handheld powered tools, such as pneumatically powered drills, which are used to drill holes for the insertion of rock-securing bolts or for the insertion of explosives to blast the product from the seam, are made for very rough handling and have to be durable. In order to be durable, pneumatic drills are made of steel, which makes them very heavy.

In the underground coal mining industry, hand-carried pneumatic drills are called stopers. Figure 1 shows this drill in operation. The stoper is used almost exclusively in a vertical orientation. Its primary function is to drill holes into the overhead rock after the coal has been removed so steel rods can be inserted to stabilize and secure the overlying rock. In the underground metal-nonmetal mining industries, the hand-carried pneumatic drills are called jackleg drills. Figure 2 shows this drill in horizontal operation. The jackleg drill is used in a variety of angles—overhead, horizontally, and downward.

The jackleg drill is used to drill holes for explosives so the ore can be blasted from the seam, as well as drilling holes for rock-securing bolts. The jackleg is bigger, heavier, and more awkward to operate than the stoping drill (stoper) that is used in underground coal mines.

Both drill types have a pneumatically operated feed leg, which is used to extend the drill body, and thus the drill steel and bit, into the rock as the holes are drilled 4 to 6 ft deep in coal mines and 4 to 12 ft deep in metal-nonmetal mines. The weight of the jackleg drill can range from 105 to 125 lb, depending on the length of its feed leg and whether the leg is made of steel or aluminum. The drill body is usually constructed of steel for durability.

The coal mine stoping drill, which is lighter than a jackleg drill, is used primarily in an overhead fashion. The jackleg drill is used at angles overhead and below horizontal; thus, for safe operation, it must be controlled with more technique and brute strength than the stoper. Inexperienced drillers often struggle against the jackleg drill during its operation, and thus impose large forces on their backs and arms.

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Figure 1.—The stoping drill is used mainly in a vertical orientation in underground coal mines.

Figure 2.—The jackleg drill is used in a variety of angles in underground metal-nonmetal mines.

RISK ANALYSIS

The MSHA data base was used to evaluate the risks of injuries related to the use of jackleg drills in the underground metal-nonmetal (MNM) mining industry during the 1978-83 6-yr period. During these 6 yr, over 4,000 accidents were reported, which resulted in over 40,000 lost workdays. The lost-day risk associated with using the jackleg drill and six other major tool categories in underground MNM mining are presented in table 1. The six other categories are included for comparison purposes.

This table indicates that the jackleg drill was involved with over 1,900 lost-time accidents. These accidents resulted in more than 18,000 total lost workdays. An average of slightly less than 10 workdays were lost for each jackleg drill accident.

Figure 3 summarizes the sequence of injury components associated with jackleg drill accidents over the 6-yr period. Over 62 pct of the injuries were due to "struck-by" types of accidents. The body parts injured most often in the struck-by accidents were the arms (39 pct), legs (23 pct), and head (22 pct). Cuts were usually sustained by these body segments (76, 63, and 54 pct) and, generally, the accidents resulted in relatively few lost days (2.5, 5.7, and 0.75, respectively). Struck-by injuries that involved a broken bone occurred most often to the trunk (23 pct), the legs (20 pct), and the arms (15 pct). These injuries usually resulted in a large number of lost days (28.2, 41.6, and 15.2, respectively).

"Caught" injuries were the next most likely type of accident to occur when using jackleg drills. The arm was involved over 91 pct of the time. These injuries usually resulted in a cut or a break. The resulting number of days lost were 5.6 and 7.7, respectively. This low number indicates that most of the injuries occurred to the hands and fingers.

Table 1.—Lost-time risk associated with hand tool use in metal-nonmetal mining, 1978-83

Tool category	Lost-time accidents	Total lost workdays	Av days lost per accident	Share of total lost days, pct
Jackleg drill	1,913	18,048	9.43	44.11
Scaling bar	1,033	16,546	16.02	40.44
Pry bar	397	2,663	6.69	6.51
Hammer and/or axe	405	1,902	4,69	4.65
Wrench	189	1,170	6.16	2.86
Knife	162	304	1.87	.74
Jack	61	283	4.64	.69
Total or av	4,160	40,916	9.84	100.00

The third most frequent accident type involved "exertion injuries." These accidents resulted in a higher number of average days lost (11.5) compared to the struck-by (9.5) and caught (6.7) type injuries. The vast majority of the exertion injuries involved the trunk (78.5 pct). Of these, 92 pct involved a muscle tear. The data for this accident type suggest that musculoskeletal injuries to the back are quite common. In fact, the overall probability value for the trunk-tear-exertion sequence (7.74 pct) is the third largest value (of the 91 entries) behind the cut-arm-struck-by sequence (18.66 pct) and the cut-leg-struck-by sequence (9.15 pct). The sequence probability concept indicates that when a lost-time injury has occurred with a jackleg drill, a tearing injury to the trunk caused by a worker's overexertion is the third most likely event that will occur.

DATA COLLECTION AND ANALYSIS

MINE STUDY

After the development of the tree-branching diagram (fig. 3), several mine visits were conducted to gather additional data. During these visits, videotapes were collected of different miners operating jackleg drills. Additionally, the drill operators were interviewed regarding their technique(s) of operating the drill. Pertinent environmental data of the mines visited were also collected in an effort to quantify any differences or similarities among them.

Analysis of the videotapes was the primary means of determining the forces that were imposed on the miner when operating the jackleg drill. As the tapes were reviewed, the body positions of each drill operator were documented. The procedure for using the jackleg drill was noted. Figure 4 presents a schematic of the usual procedure for using a jackleg drill.

A detailed task analysis was conducted on each operator videotaped. The tasks that required heavy muscular effort on the part of the operator were identified. Body segment angles and the direction of the forces that were exerted while using the drill were documented.

After the overall body posture and the position of the body segments were noted, these postures were further analyzed with a static strength model. This permitted an initial estimate of the loadings and the forces imposed on various body joints, such as the shoulder, elbow, hip, knee, and the L_5-S_1 intervertebral disk. These estimates were related to overall body anthropometry (height, weight, and estimate of body morphology). The resultant joint loadings were compared to the strength capabilities of the general population. In addition, the loading on the lower back (L_5-S_1 disk) was compared to the action limit and the maximum permissible limit recommended by the National Institute for Occupational Safety and Health.

Along with the task analysis and the biomechanical evaluation, the narratives associated with selected accidents were reviewed. Although these narratives were only brief descriptions (two or three sentences) of the accident, they often permitted the main problem of that accident to be identified.

Four main tasks were identified on the videotapes that involved heavy muscular effort. These included carrying the drill into the workplace, positioning the drill steel against the rock face, collaring the drill hole (just beginning to start a hole, perhaps only 1/2 in deep), and removing the drill steel after the hole was completed. Drilling the hole was not included with these tasks because the actual drilling does not really involve any heavy muscular forces.

From these extensive analyses, different hypotheses related to accident possibilities were developed, discussed, and evaluated. Hypotheses were developed for the four tasks that involved heavy muscular effort (carrying, positioning, collaring, and removal).

In addition, the videotapes revealed that inserting the drill steel into the drill chuck had to be done with one hand

(MNM) Jackleg drill: N=1,913, TDL=16,046, Mean=9.434

Accident type	Body part	Nature	N	(Prob.)	Mean	Sq. dl.	Sq. pr.
Caught: N=318, TDL=2,126, Mean=6.69, (0.166)	Arm: N=290, TDL=1,884, Mean=8.50, (0.912)	b:	77,	(0.266),	7.69,	592.1,	0.0403
		c:	188,	(0.572),	5.63,	934.6,	0.0868
		m:	38,	(0.131),	7.13,	271.0,	0.0199
		o:	4,	(0.014),	6.50,	28.0,	0.0021
		t:	5,	(0.017),	12.00,	60.0,	0.0026
	Head: N=3, TDL=59, Mean=19.67, (0.009)	c:	2,	(0.667),	14.00,	28.0,	0.0010
		m:	1,	(0.333),	31.00,	31.0,	0.0005
	Leg: N=12, TDL=96, Mean=8.0, (0.038)	b:	1,	(0.083),	0.00,	0.0,	0.0005
		c:	8,	(0.667),	10.00,	80.0,	0.0042
		t:	3,	(0.250),	5.33,	16.0,	0.0016
	Multiple: N=5, TDL=8, Mean=1.2, (0.016)	c:	1,	(0.200),	1.00,	1.0,	0.0005
		m:	2,	(0.400),	0.00,	0.0,	0.0010
		t:	2,	(0.400),	2.50,	5.0,	0.0010
	Trunk: N=8, TDL=81, Mean=10.13, (0.025)	b:	1,	(0.125),	28.00,	28.0,	0.0005
		c:	4,	(0.500),	5.75,	23.0,	0.0021
		m:	1,	(0.125),	0.00,	0.0,	0.0005
		t:	2,	(0.250),	15.00,	30.0,	0.0010
Exertion: N=205, TDL=2,360, Mean=11.51, (0.107)	Arm: N=29, TDL=593, Mean=20.45, (0.141)	b:	1,	(0.034),	0.00,	0.0,	0.0005
		m:	2,	(0.069),	39.00,	78.0,	0.0010
		o:	14,	(0.483),	33.64,	471.0,	0.0073
		t:	12,	(0.414),	3.67,	44.0,	0.0063
	Leg: N=9, TDL=123, Mean=13.67, (0.044)	t:	9,	(1.000),	13.67,	123.0,	0.0047
	Multiple: N=4, TDL=10, Mean=2.50, (0.020)	t:	4,	(1.000),	2.50,	10.0,	0.0021
	Neck: N=2, TDL=47, Mean=23.5, (0.010)	o:	1,	(0.500),	0.00,	0.0,	0.0005
		t:	1,	(0.500),	47.00,	47.0,	0.0005
	Trunk: N=181, TDL=1,587, Mean=9.86, (0.785)	b:	1,	(0.006),	6.00,	6.0,	0.0005
		c:	3,	(0.019),	4.00,	12.0,	0.0018
		o:	9,	(0.056),	11.44,	103.0,	0.0047
		t:	148,	(0.919),	9.91,	1,466.7,	0.0774
Fell: N=152, TDL=1,907, Mean=12.55, (0.079)	Arm: N=47, TDL=221, Mean=4.7, (0.309)	b:	7,	(0.149),	7.86,	55.0,	0.0037
		c:	36,	(0.766),	0.47,	16.9,	0.0188
		m:	2,	(0.043),	62.50,	125.0,	0.0010
		t:	2,	(0.043),	12.00,	24.0,	0.0010
	Head: N=6, TDL=9, Mean=1.5, (0.039)	c:	5,	(0.833),	1.60,	8.0,	0.0028
		m:	1,	(0.167),	1.00,	1.0,	0.0005
	Leg: N=27, TDL=191, Mean=7.07, (0.178)	b:	6,	(0.222),	15.67,	94.0,	0.0031
		c:	5,	(0.185),	1.40,	7.0,	0.0026
		m:	3,	(0.111),	5.33,	16.0,	0.0016
		o:	4,	(0.148),	4.00,	16.0,	0.0021
		t:	9,	(0.333),	6.44,	58.0,	0.0047
	Multiple: N=10, TDL=317, Mean=31.7, (0.066)	c:	2,	(0.200),	11.50,	23.0,	0.0010
		m:	6,	(0.800),	41.33,	248.0,	0.0031
		t:	2,	(0.200),	23.00,	48.0,	0.0010
	Neck: N=1, TDL=5, Mean=5.0, (0.007)	t:	1,	(1.000),	5.00,	5.0,	0.0005
	Trunk: N=81, TDL=1,184, Mean=19.0, (0.401)	b:	7,	(0.115),	23.71,	168.0,	0.0037
		c:	11,	(0.180),	8.00,	88.0,	0.0058
		m:	4,	(0.066),	20.25,	81.0,	0.0021
		o:	9,	(0.148),	35.00,	315.0,	0.0047
		t:	30,	(0.492),	17.87,	536.1,	0.0157

Figure 3.—Tree-branching diagram showing the sequence of injury components associated with jackleg drill accidents in underground metal-nonmetal mining for the 1978-83 period.

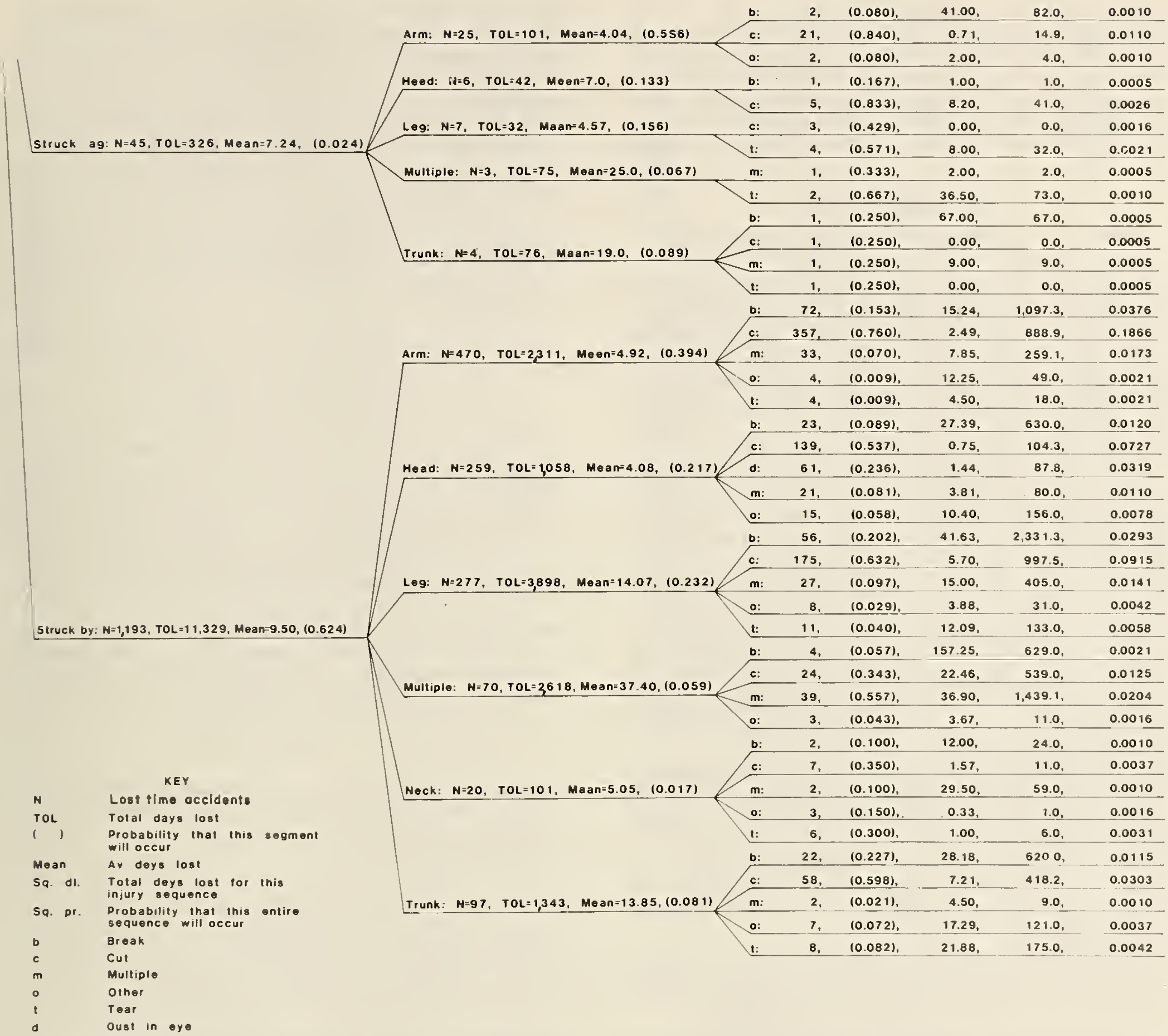

Figure 3.—Tree-branching diagram showing the sequence of injury components associated with jackleg drill accidents in underground metal-nonmetal mining for the 1978-83 period—Continued.

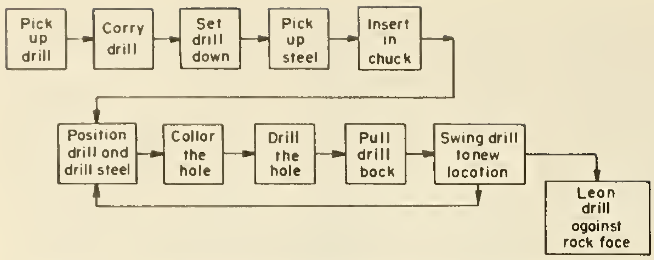

Figure 4.—Typical procedure for using the jackleg drill.

(usually the left), while the other hand supported and balanced the drill. Essentially, the miner would throw the drill steel up in the air and would catch it further down its length so it could be inserted in the drill. Thus, these five elements of the jackleg drill operation were included in the development of hypotheses related to accident possibilities. The following is a partial listing of the questions developed for the five elements.

1. *Carrying the drill.*—Because the jackleg drill typically weighs over 110 lb, the manner in which it is handled can have a definite impact on the operator. The drill is usually carried either by resting the leg on the shoulder, or cradling the drill with one arm and gripping the "D" handle on the feed leg with the other hand. The first method results in large shear forces on the spine, and high static force requirements on the muscles of the lower back. The second method allows the drill to be carried closer to the body, thereby minimizing the forward torque. Modification of the carrying method through placement of a handle on the drill body or a carrying strap may reduce the loading placed on the operator.

(a) Will the addition of a handle, which would be located on the top of the drill casing and in front of the feedleg connection, reduce the muscular forces required to carry the drill?

(b) Would the addition of a carrying strap that is designed to go around the back of the neck reduce the biomechanical and/or physiological requirements, when carrying the drill?

(c) Can a recommended method, supported by muscle electrical activity, be developed so muscular force requirements are minimized, thus reducing the risks of injury when the drill is lowered from the shoulder?

2. *Inserting the drill steel.*—The typical method involves supporting the drill with one hand, while throwing the drill steel up and catching it near the lower end with the other hand. This can cause a large unexpected loading to the forearm if the steel moves to a less vertical orientation. Supporting the drill steel at the lower end with only one hand places significant torque about the wrist. Hence, this method of handling drill steels should be of concern with respect to cumulative trauma disorders. Although this technique may not be a direct cause of arm exertion injuries, the repeated loadings on the hand, wrist, forearm, and elbow maybe a contributing cause for other arm injuries.

(a) Which muscles and joints are primarily affected by the forces imposed by this particular method of handling the drill steels?

(b) Are miners prepared for unexpected loadings on the wrist if the drill steel moves into a nonvertical position when it is thrown upward?

3. *Positioning the drill.*—Positioning the drill involves the miner balancing it with one hand, while manipulating it toward the rock face to be drilled with the other hand. This task element involves the miner counteracting expected and unexpected forward and possibly sideways movements caused by the instability of the drill. A sampling of the accident narratives indicated that trunk exertion injuries occurred when miners attempted to prevent drills from falling. Research[6] has indicated that the effect of unexpected loading essentially makes the muscles respond the same as they would to twice the weight of an expected loading. Thus, an unexpected 10-lb load elicits a muscle response that is the same as that generated by a 20-lb expected loading. Modifications to the tool design or the method of use may be developed that will reduce the possibility of large unexpected loads and the associated exertion injuries.

(a) Can the muscular forces required during drill positioning be reduced by the addition of a handle on top of the drill casing in front of the feed leg connection?

(b) Will the time required to position the drill bit be reduced with the addition of the handle on the drill?

4. *Collaring the hole.*—Collaring the hole, which is getting the hole started to a depth of just 1/2 in or so, requires the drill operator to assume a static working posture. The maximal force that a miner can exert, therefore, will decrease rapidly with the time required for collaring. While the hole is being collared, the operator has to hold the drill steel with the left hand and stabilize the tool with the other. Once the drill steel and bit are positioned against the rock face, the left hand is removed from the drill steel and is used to turn the drill to low speed to begin moderate drilling. Measurements of muscle activity will be useful to establish the relative force requirements, and the role of fatigue in different collaring techniques.

(a) Can various stances be used effectively when collaring a drill hole?

(b) Are there optimal body positions for different hole heights that will minimize the strength requirements to effectively collar the hole?

5. *Removing the drill steel.*—A sampling of the narratives of the jackleg accidents indicate that exertion injuries are related to drill steel removal. The videotapes revealed that the drill operators jerked on the drill one to three times to pull the steel and bit from the completed hole. The lower holes represented more of a problem because the bit can become jammed in the hole because of the rock cuttings. Additionally, more strength is required to pull the drill steel free of a lower hole because the weight of the drill has to be lifted at the same time the drill steel is being jerked free. Finally, when pulling the drill steel and bit free of a hole that is angled downward, the posture of the drill operator is flexed forward severely. The jerking actions can cause intense loading to the lumbar spine.

(a) Will the addition of the handle to the drill casing make it easier to pull the drill steel free from a lower hole?

(b) Can suggestions be made to the usual method of pulling the drill steel out of lower holes that will decrease the loading to the operator's lower back?

In summary, consideration of the developed hypotheses indicated that excessive muscle forces are routinely experienced. Asymmetrical loading occurs to the drill operator's back because of the weight and instability of the jackleg drill, and also because of the bulkiness of the 2-in air line that is attached to the right side of the drill. Also, unexpected loadings occur quite easily and frequently.

[6] Marras, W. S., S. L. Rangarajuly, and S. A. Lavender. Trunk Loading and Expectation, *Ergonomics*, v. 30, No. 3, 1987, pp. 549-560.

When the drill slips and starts to fall, the operator usually tries to prevent it from falling. The arms, shoulders, and upper and lower back can be easily stressed quite dramatically by this reflex action. Additionally, the dynamics of the task or actions of the opertor trying to prevent an accident can cause severe loading from overcompensation or the excessive co-activation of the agonist-antagonist muscle pairs.

After extensive analysis and consideration, the researchers feel that many of the struck-by accidents are related to insufficient trunk strength. Because of unexpected or excessive loadings, and a corresponding inadequate back strength, the drill or drill steel can impact the arm, leg, head, or neck. Thus, the root of the problem may be insufficient muscle control or excessive fatigue.

LABORATORY STUDY

To investigate the hypotheses that were developed, a laboratory experiment has been developed. The objective of the experiment is to interpret the trunk muscle loadings that occur during the four task elements that have been identified as requiring heavy muscular effort for their completion. A handle has been designed and fabricated for the drill casing; it is positioned on the drill body in front of the feed leg connection. Electromyographic (EMG) data have been collected from six trunk muscles—the right and left latissimus dorsi (RLD and LLD), right and left erector spinae (RES and LES), and right and left rectus abdominus (RRA and LRA)—from eight test subjects.

Subjects

At the time this paper was prepared, six of the eight test subjects had been tested. The eight subjects are not miners, but all are familiar with typical underground mining conditions. As such, however, the subjects are novices, and all require some training with the jackleg drill so it can be operated safely. The test subjects will range in age from 23 to 39, and all are greater than the 50th percentile in height and weight. All subjects are in good physical condition and none has a history of significant back problems. All subjects are volunteers; each is required to fill out an informed consent form and complete a medical history form.

Test Apparatus

A simulated underground mine workplace was constructed at Ohio State University for this investigation. The underground workplace, shown in figure 5, consisted of an adjustable-height roof; a simulated rock face for use in positioning, collaring, and removing the drill steel; and a floor that consisted of 4 in of loose rock and gravel. The room in which the simulated workplace was constructed was 28 ft long, 10 ft wide and 11-1/2 ft high. The simulated work area was approximately 12-1/2 ft long and 7 ft wide.

The simulated rock face consisted of a wall of standard 2- by 4-in studs, 10 ft in length, nailed together face to face; thus the drill rested against the edges of the 2 by 4's. This wall consisted of 44 studs nailed together. The overall dimensions of the simulated rock face were 5-ft width, 10-ft height, and 3-3/8-in thickness (actual dimensions of a 2- by 4-in stud are 1-3/8 by 3-3/8-in).

A series of eight holes were drilled into the simulated face. Four of them were drilled entirely through the wall and the other four were drilled only halfway into it. The holes were located at heights of 22, 43, 68, and 92 in above the rock and gravel floor.

Large pipe caps were placed into the holes that were drilled halfway through the wall. This arrangement was used for the collaring element of the simulation. A drill steel with no bit on it was positioned inside a pipe cap, and the drill was set at a low speed, as if a drill hole was to be started (collared). The holes that were drilled entirely through the

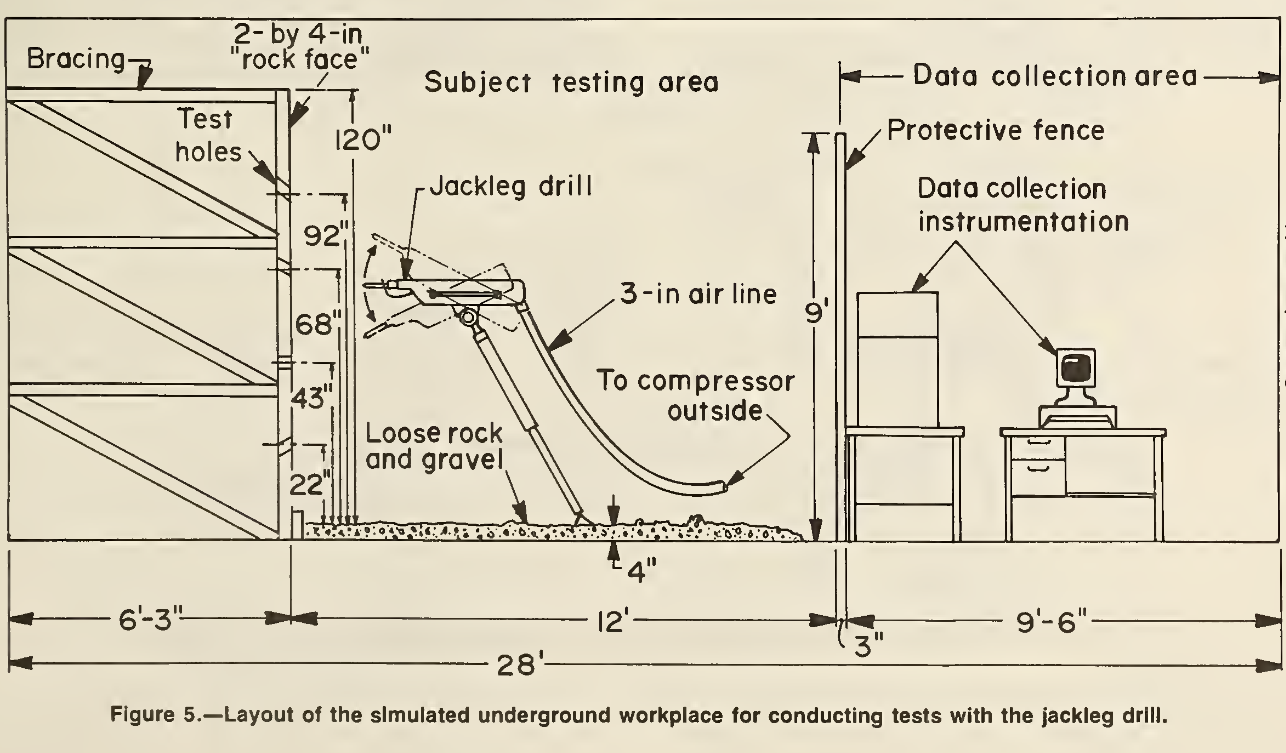

Figure 5.—Layout of the simulated underground workplace for conducting tests with the jackleg drill.

wall were used to simulate the positioning and removal elements.

Bracing for the simulated face took up 6 ft of the room. The other 9 1/2 ft of the room contained the data collection instrumentation. A protective metal fence separated the simulated workplace from the data collection portion of the room.

Experimental Design

The independent variables for this experiment were the hole heights and the presence or absence of the handle that was fabricated for the drill casing. Three of the four hole heights were used during the testing. The 22-in height was used for the lower hole simulation. The 43-in height was used for the horizontal work, and the 92-in height was used for the overhead hole positioning, collaring, and removal. The dependent variable was the EMG activity of the six trunk muscles for each of the four elements (carrying the drill, positioning the drill steel, collaring the hole, and removing the drill steel).

As mentioned, all subjects were familiar with the underground mining environment, but were novices regarding the operation of a jackleg drill. All subjects were required to go through one to three training sessions to become familiar with the safe operation of this drill.

Data Collection Equipment

The surface EMG electrodes were attached to the subject's torso at the six muscle sites (right and left latissimus dorsi, erector spinae, and rectus abdominus). The location of the electrodes was verified through functional muscle testing. The electrode locations and attachments were prepared according to standard procedures.[7] Skin resistance was measured to verify the conductivity of the electrode-skin attachment. The electrodes were connected to small lightweight preamplifers that were attached with Velcro[8] hook-and-loop fasteners to a belt around the subject's waist. This assured that the electrodes were in close proximity to the preamplifiers to reduce any interference in the EMG signal.

Six pairs of electrodes and one ground electrode were connected to the EMG amplifiers. The EMG signal was conditioned with high- and low-pass filters and integrated by a hardware root-mean-square (RMS) procedure. The six EMG signals were monitored by an ISAAC 2000 data acquisition system. This system uses a microprocessor to convert analog signals to digital form. A Schmitt trigger was incorporated into the data collection system to document the temporal aspects of the experiment.

After each experimental trial, the data were transferred to a microcomputer for viewing on a graphics display. This ensured that all signals were active throughout each portion of the experiment. The data were then stored for further analysis. Figure 6 presents a schematic of the data acquisition system.

Experimental Task

The subjects were asked to warm up by bending and stretching before beginning the experiment. Before the actual testing, a pretest was conducted. The pretest consisted of recording the maximum voluntary contraction, as well as the resting levels, of each muscle group.

During the testing, each subject performed the following tasks: (1) pick up the jackleg drill, carry it approximately 10 ft, set it down and lean it against the simulated face; (2) insert the drill steel (with no bit) into the three holes (22-, 43-, and 92-in heights) with pipe caps inserted into them so the drill could be started as if the holes were being collared; (3) balance the drill and insert the drill steel into the holes (at the same three heights) that were drilled through the wall, and extend the feed leg so the drill body touches the wall; (4) release the feed leg so the drill could be pulled away from the wall, and remove the drill steel from the same three holes. These task elements were randomized to reduce any bias from order of conducting the tasks. Two repetitions of each task element were recorded, and a 2-min rest period was provided between exertions.

[7] Basmajian, J. V. Muscles Alive: Their Functions Revealed by Electromyography. William and Wilkins, 1979, 561 pp.

[8] Reference to specific products does not imply endorsement by the Bureau of Mines.

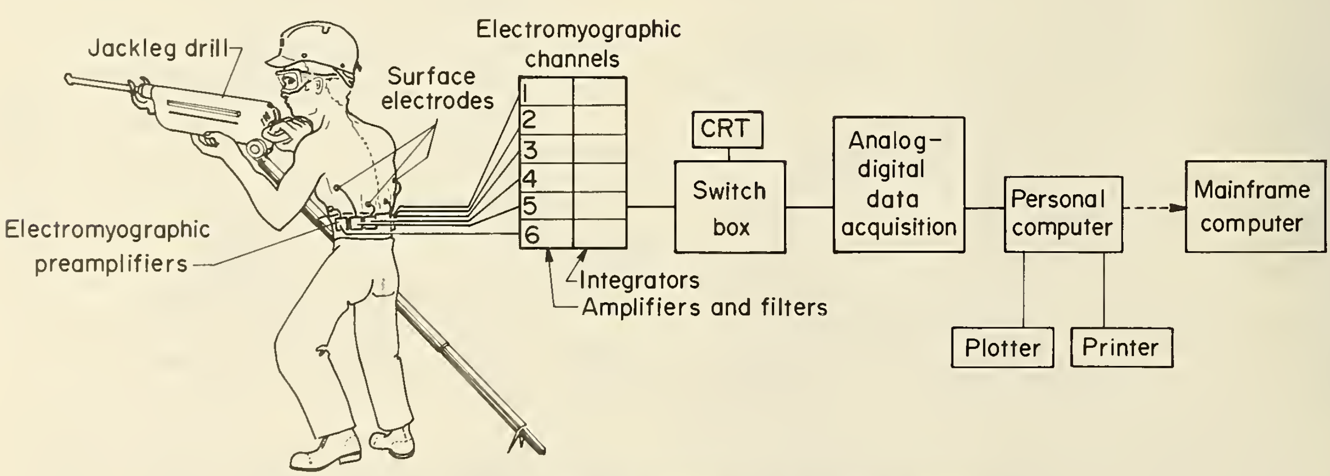

Figure 6.—Data acquisition system for the jackleg drill testing.

PRELIMINARY RESULTS

As mentioned in the previous section, six of the scheduled eight subjects had been tested at the time this paper was prepared. Additionally, only data from the first subject had been analyzed. As such, the analysis obtained thus far is quite preliminary and no trends can be identified just yet. Figures 7 and 8 are presented to show typical EMG data obtained during the testing. Figure 7 presents the electrical activity from the three muscle groups when collaring the low hole (22-in height). Figure 8 presents EMG data for the trunk muscles of the same subject but collaring the high hole (92-in height).

Figure 7 shows a distinctive double peak in the muscle activity. The initial burst of activity relates to orienting the drill steel into the lower pipe cap. The low activity in the middle of the sample is when the drill is turned to a low speed to simulate the collaring of the hole. The second burst of muscular activity occurs after the drill is turned off and then pulled back from the face. During this exertion, the RLD and the RES muscles exhibited a very dramatic rise in electrical activity. The LLD and LES developed the next highest activity. Both abdominal muscles showed very little activity during this entire task.

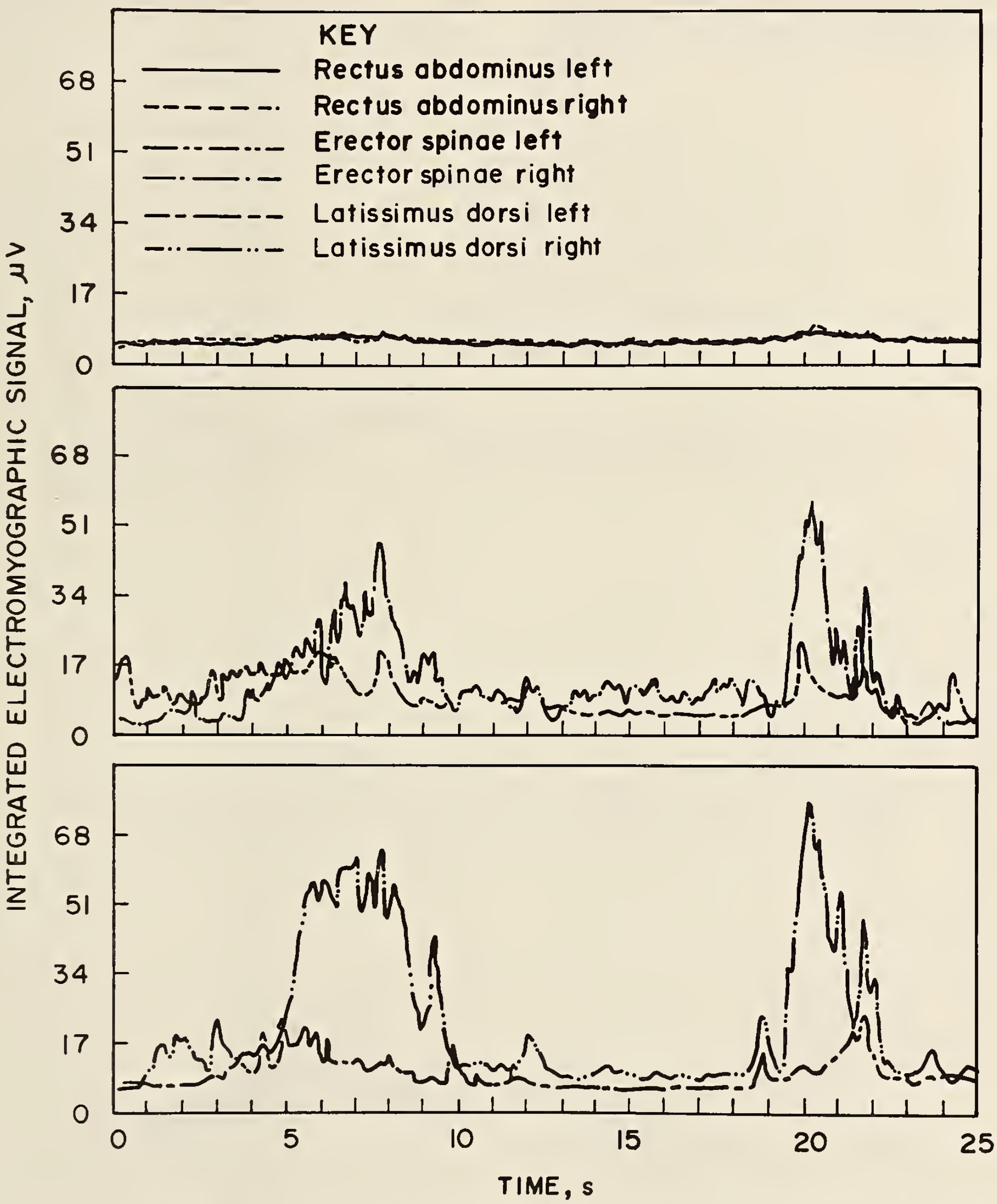

Figure 7.—Integrated EMG data for six trunk muscles of one subject while handling the jackleg drill at low-hole height (22 in).

Figure 8 shows that the initial burst of muscle activity occurs more rapidly for the high hole than the low hole, but the peak value for the high hole is 56 μV versus 64 μV for the low hole. Again the initial electrical activity involves the RLD and the RES during the drill steel orienting. Similar to figure 7, the LLD and LES are the next most active, and the abdominal muscles were fairly inactive.

The middle portion of the overall exertion was quite different in this figure. Much more activity was exhibited for the high hole than the low hole. The beginning of the collaring had the RLD and LES the most active. Rather quickly, however, the activity of the LLD exceeded that of the LES. In fact, for a brief 3-s interval, the electrical activity of both of the abdominal muscles exceeded the activity of both erectores.

The second activity (pulling the drill back from the face) is not as clearly delineated for the high hole. This is consistent with the accident narratives and the developed hypotheses. The major effort for pulling the drill back from the face occurs much more noticeably for the lower holes. At 17 s lapsed time, there are slight peaks for the RLD and both erector spinae muscles. At the same time, the activity for the two abdominals drops off quite noticeably. Looking at the low-hole data, the RLD and RES muscles are the most active throughout this entire task. This seems to indicate definite asymmetrical loading.

For the high hole, the RLD dominates throughout the task. The RES starts out with the second highest activity, but within a few seconds, the electrical activity of the LES clearly exceeds the RES and for a brief while is as active as the RLD. Approximately halfway through the task the activity of the LLD increases steadily and actually exceeds that of the RLD for 3 s or so. At 17 s lapsed time (when the drill is pulled back from the face), the LLD drops off quite noticeably.

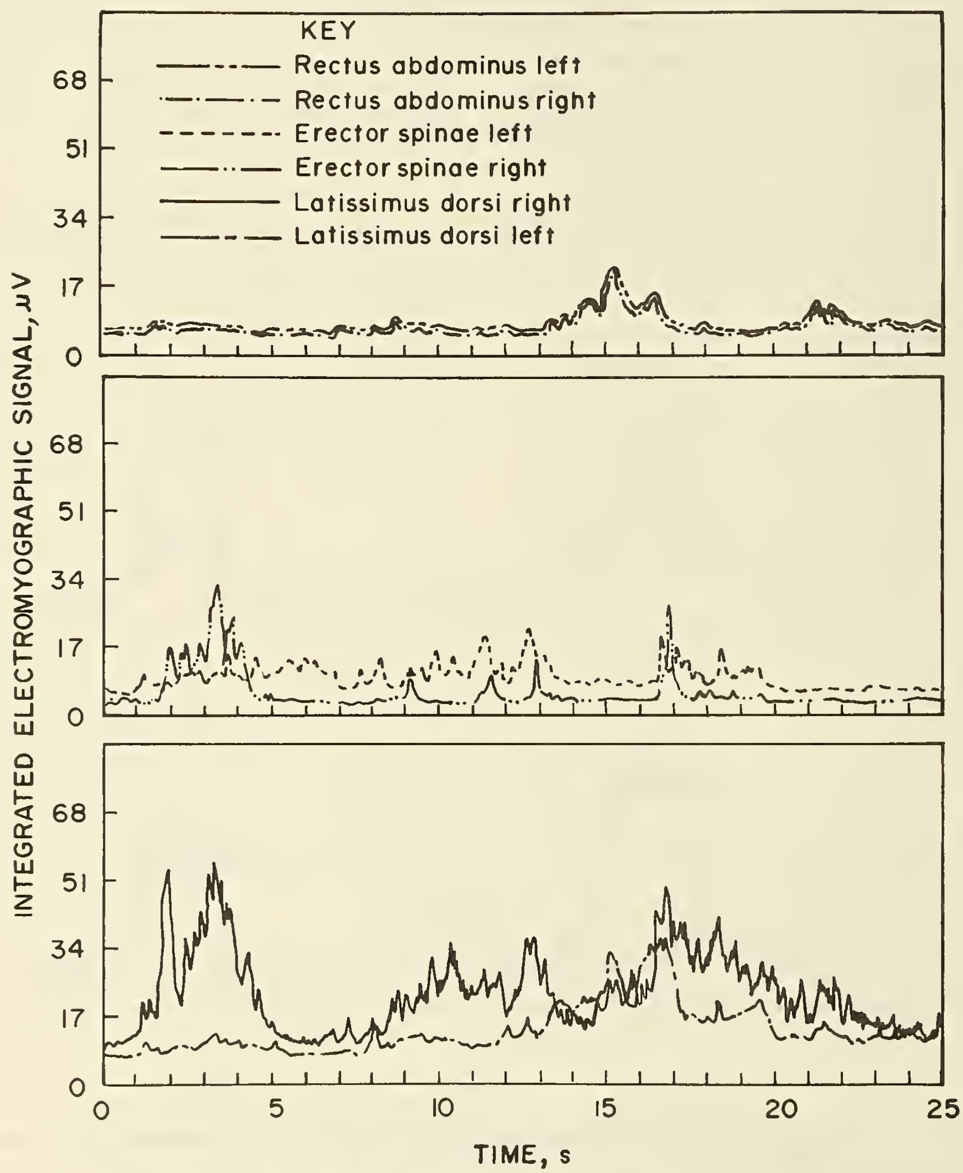

Figure 8.—Integrated EMG data for six trunk muscles of one subject while handling the jackleg drill at high-hole height (92 in).

SUMMARY

The task analyses have identified problem areas associated with using the jackleg drill. The hypotheses that have been developed have helped to focus the methods with which these problems can be addressed and researched in controlled laboratory conditions.

Although only two EMG graphs are presented, they give some indication as to the muscular activity required when operating the jackleg drill. Asymmetric loading is indicated during the manipulation of the drill at the low-hole height (22 in).

Data analysis has not been completed for the conditions with the handle attached to the drill casing. Responses from four of the six test subjects, however, have been favorable. All six subjects feel as if the addition of the handle makes it easier to pull the drill steel out of the lower hole.

COMPUTER-AIDED ANALYSIS OF HUMAN FACTORS ASPECTS OF MINING CREWSTATIONS

By Richard L. Unger[1] and James P. Rider[2]

ABSTRACT

The Bureau of Mines is researching a computer-aided analysis model for mining machine operator compartments. Based on proven models used in both the public and private sectors, and original software being developed by the Bureau, the model will perform the following: reach assessment, visibility analysis, structural analysis of protective canopy designs, illumination analysis (including both disability and discomfort glare ratings), operator fatigue analysis, and computation of an ingress-egress rating. The model will make extensive use of graphics to simplify data input and output. A three-dimensional manikin is used as the subject for many of the analyses. The model is intended for use by equipment manufacturers and mining companies during initial design work on new machines, and for evaluating proposed modifications to existing machines. The Bureau also plans to use the model as an accident investigation tool, where it can be used to reconstruct the events leading to certain equipment-related accidents.

INTRODUCTION

Use of computers is becoming an increasingly acceptable technique for equipment designers. Computer-aided design (CAD) replaces the traditional drawing board with a graphics monitor and input device.

By using the computer, the designer has a flexibility to experiment that is not practical with conventional techniques. Drawing information is stored in a data file *and* simultaneously displayed to the designer. The design process is accelerated by the speed with which the computer converts the designer's input into digital form, with an accuracy difficult to achieve with a pencil or pen. Once created, drawings can be scaled and plotted in seconds.

Modifications and changes can be made with even greater efficiency. Changing one element of a shape for example, can automatically result in suitable changes in all other related lines and dimensions of that shape. The size of an object can be scaled up or down instantly. Once drawn on the CAD system, any object can be recalled, rescaled, and added to a new design without tedious redrawing.

Through use of a CAD system, a designer's productivity can be increased significantly. There is no doubt that CAD is the way of the future and will eventually replace the manual drafting board in most engineering offices. As it relates to the human engineering of equipment, CAD can provide assistance by displaying three-dimensional views of objects and assemblies, so that the designer can better visualize potential problem areas. Unfortunately, while CAD systems make the design process more efficient, their use can lead to problems.

The environment of the CAD facility promotes work output and efficiency, but not thought and consideration. The CAD system usually incorporates a very expensive workstation, and designers oftentimes must schedule time on the system. Two- and three-shift utilization of CAD facilities is not uncommon. This situation does not promote the long periods of contemplation that designers have traditionally indulged in while working at their drawing board. Also, a designer would rarely leave a CAD display running to go back and review a design reference manual. Rather, the designer would most likely make a note to look up the information and perhaps correct the problem at a later session. So, while the CAD system is a tool of unprecedented power and capability, the designer is pressed by that same power to avoid the pauses associated with *consideration* (*1*).[3]

Another problem is that CAD systems usually provide no means to consider the interface between the equipment being designed and the operator who is using it. The traditional method of doing this is to build mockups and perform "fitting trials," using a sample of the eventual operators

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[3]Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this paper.

of the equipment. This approach is necessary to ensure that a design meets accepted human engineering specifications. However, because of the time and expense involved, it often means that many parts of the design are finalized without consideration of the human operator (*2*).

The design of underground mining machinery has generally stressed the technical and engineering aspects related to the machine's functions over the needs of its human operators. This has resulted in machines that strain the capabilities of their operators and contribute to the high accident rate among operators or riders of underground coal mobile equipment. As an example, in 1984 there were 1,822 injuries to miners while operating or riding in underground mobile equipment. This amounts to 17 pct of all the injuries that occurred in underground coal mining during that year.

In many cases the injuries can be directly related to the design of the machine operator compartments. As shown in figure 1, oftentimes operators must lean outside the safe confines of the vehicle compartment in order to operate the vehicle, thereby increasing the likelihood of their striking the rib or roof. Controls are often unlabeled and placed where they are difficult to reach and distinguish from one another. In panic situations, the wrong control may be activated, which could lead to accidents or injuries.

In order to address these problems, the Bureau is developing a computer-based model to aid in the human engineering aspects of mining equipment design. The model, known as crewstation analysis programs (CAP), is now in the middle stages of a 10-yr development program. It is intended for use by original equipment manufacturers and mining companies for the initial design work on new machines, and to evaluate proposed modifications to existing machines based on good ergonomic design principles.

The purpose of this paper is to outline the overall structure of CAP and provide background on two of its analysis sections, specifically, the visibility analysis and the illumination analysis. Interested readers are invited to contact the Bureau of Mines, Pittsburgh Research Center, for more information on the CAP model.

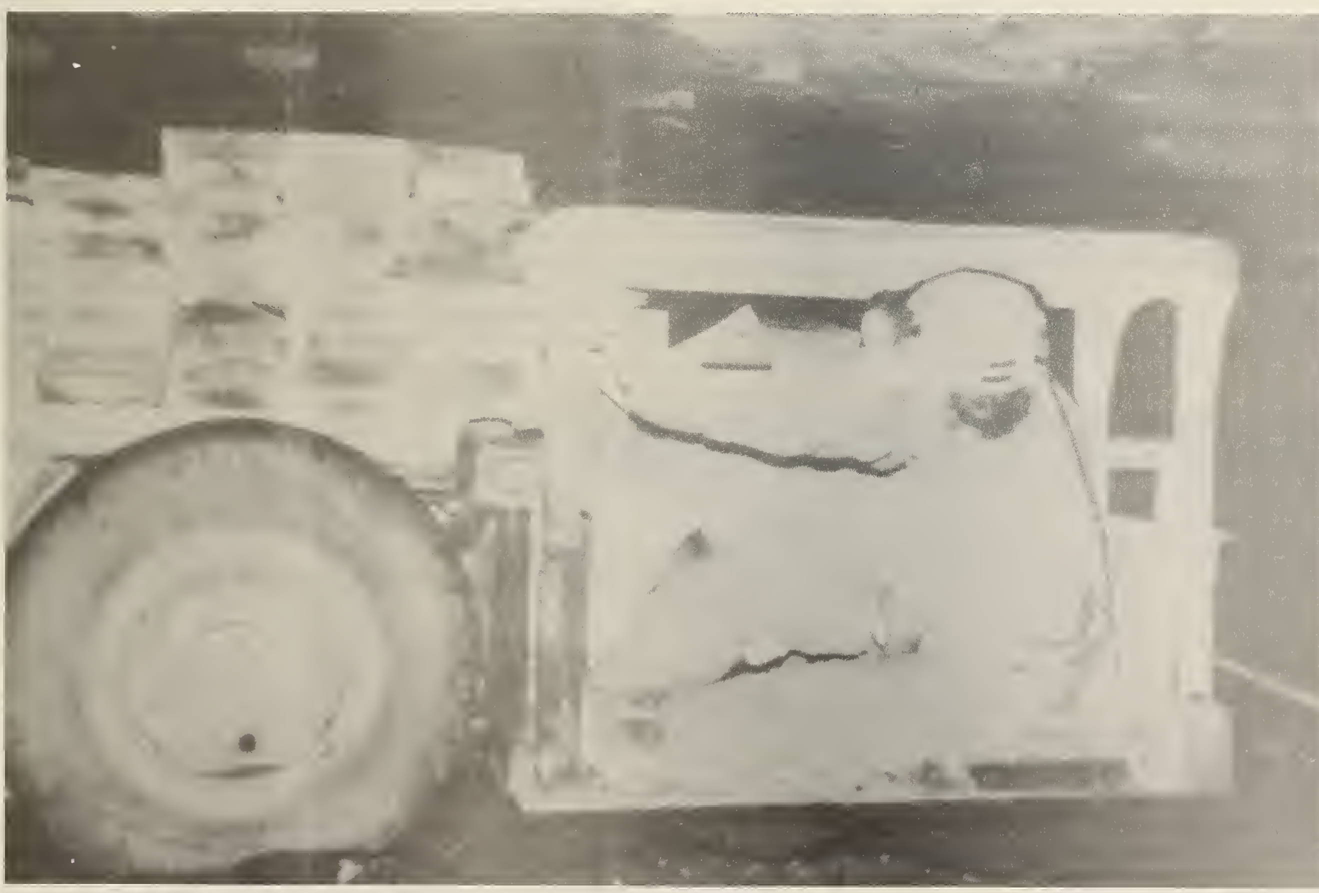

Figure 1.—Cramped operator stations and poor visibility often force miners to lean outside the safe confines of the cab.

OVERVIEW OF CAP

When work on this project began, it was decided to take advantage of as much publicly available software as possible. This was to both keep the final cost of the model low, and avoid spending time in unnecessarily repeating the work of others. Original software developed by the Bureau under its health and safety research program is free to the public upon its completion, so the final cost of implementing CAP at a particular site will consist mainly of the expenses of the hardware needed.

CAP is designed to work with Tektronix computer display terminals (model 4111), hard copy units, and graphics tablets[4] as shown in figure 2. Some sections of the model require no graphics and can be run on virtually any terminal. CAP is written in Fortran and is currently implemented on a VAX 780 and Microvax II computer network at the Bureau's Pittsburgh Research Center.

For the sake of simplicity, CAP can be thought of as being composed of the following major analysis sections, as shown in figure 3.

1. Anthropometric (reach) analysis.
2. Visibility analysis.
3. Illumination analysis.
4. Canopy structural analysis.

The first section determines whether the controls are reachable for a given sample population and provides information for the best positioning of controls. The fourth analysis section determines if the protective canopy meets the requirements of the Federal Coal Mine Health and Safety Act of 1969. The applications of the visibility and illumination analyses sections are discussed in detail later in this paper.

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

In addition, research related to the model is continuing and the following sections will be added:

5. Fatigue analysis.—Assigns a numerical value for rating the overall positioning of an operator in a particular crewstation.
6. Dynamic positioning and timing of movements analysis.—Measures the ability of an operator to exit the cab and the time required to reach designated controls.

Each of these six sections address an important aspect of the machine's design with respect to human engineering.

Before any analysis can begin, data defining the mining machine, mine layout, or population sample must be entered into the computer. CAP will allow two techniques for constructing three-dimensional models of mining machines and operator compartments. The first method, not yet implemented, is to build the model using three-dimensional body types such as blocks, wedges, cones, elliptical cylinders, and spheres as shown in figure 4 and table 1. The user defines the dimensions of each body type and its orientation in a three-dimensional coordinate system. In this way, combinations of shapes can be used to construct practically any geometry needed to perform an analysis. As an example, figure 5 is a photograph of an underground forklift developed by the Bureau and figure 6 is the three-dimensional model of the forklift constructed using the preceding technique.

The major drawback to this construction method is that it is time consuming for the user to compute the sizes and locations of the shapes needed, and then to input them into the computer. For this reason, a second machine geometry method is being provided.

Figure 2.—Some of the computer graphics equipment used for the CAP model.

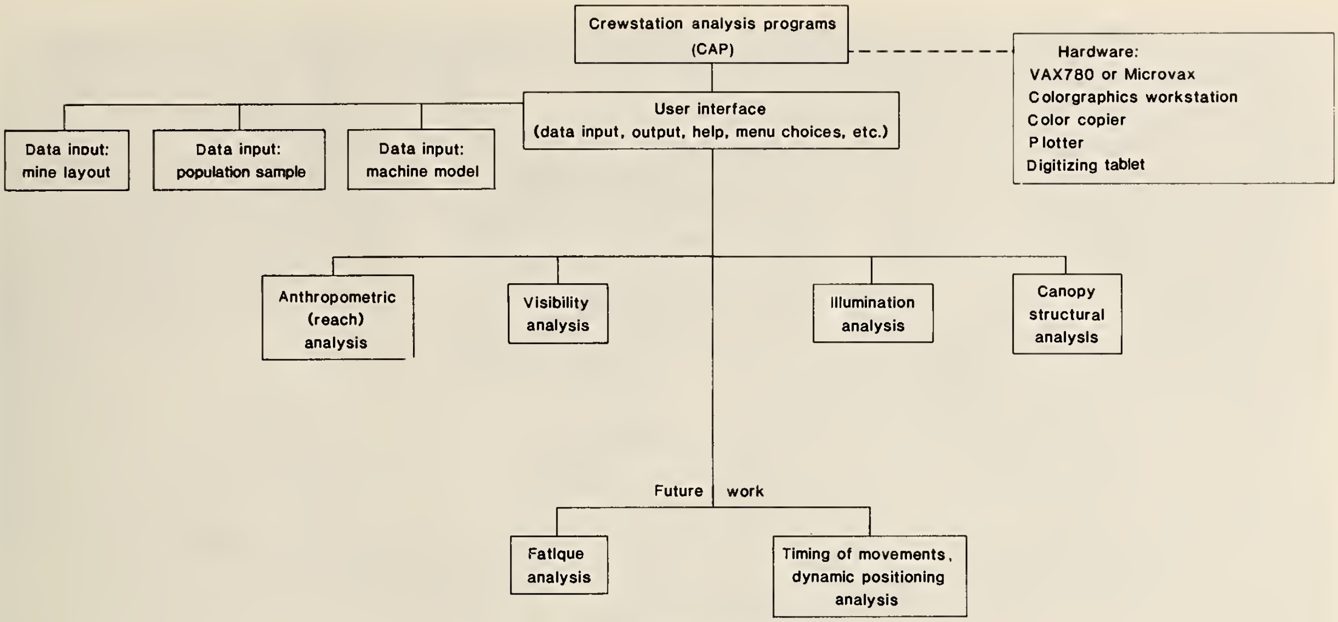

Figure 3.—Overview of CAP.

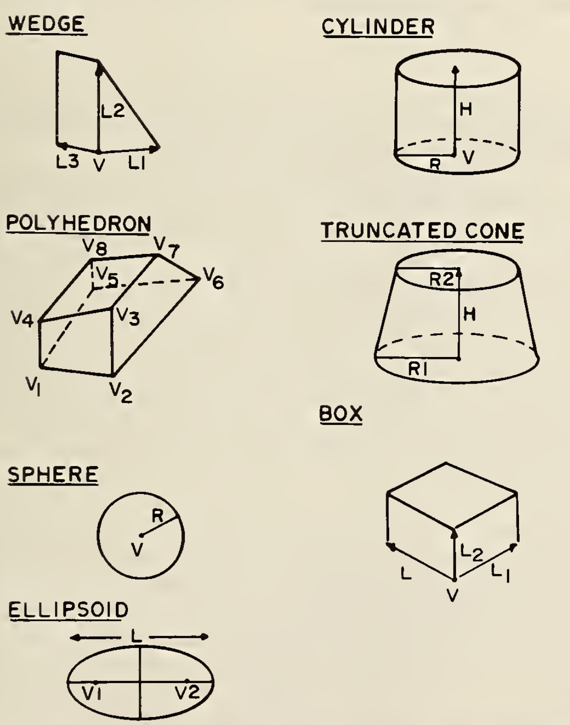

Figure 4.—Body types used in machine model construction.

Table 1.—Body type, description, and input parameters[1]

Body type	Description	Parameters
Box	6-sided parallelepiped	V_x, V_y, V_z. $L1_x$, $L1_y$, $L1_z$. $L2_x$, $L2_y$, $L2_z$. $L3_x$, $L3_y$, $L3_z$.
Wedge	A "box" cut along a diagonal.	V_x, V_y, V_z. $L1_x$, $L1_y$, $L1_z$. $L2_x$, $L2_y$, $L2_z$. $L3_x$, $L3_y$, $L3_z$.
Polyhedron	6-sided convex figure........	Vn_x, Vn_y, Vn_z, where n = 1 to 8; also faces 1 through 6, where the face value is given by the cardinal numbers of its 4 vertices.
Sphere.........	A rotated circle defined by its center and radius.	V_x, V_y, V_z. R.
Ellipsoid........	A rotate ellipse defined by its two foci and the length of its major axis.	$V1_x$, $V1_y$, $V1_z$. $V2_x$, $V2_y$, $V2_z$. L.
Cylinder........	A projected circle	V_x, V_y, V_z. H_x, H_y, H_z. R.
Truncated cone.	Similar to a cylinder, but with a second radius specified.	V_x, V_y, V_z. H_x, H_y, H_z. R1, R2.

[1]See figure 4 for identification of parameters.

Figure 5.—Prototype battery-powered underground forklift.

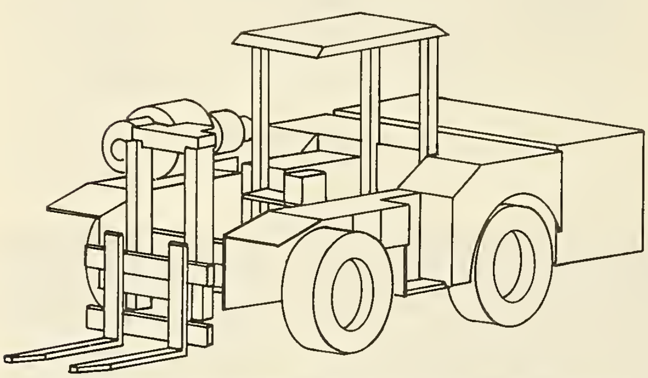

Figure 6.—Three-dimensional model of a forklift created using method 1.

This second method makes use of a graphics tablet to digitize significant points from orthographic projection drawings of the desired machine as shown in figure 7. The digitized points are stored for later use in a routine that will convert the two-dimensional drawings into a three-dimensional object. The greatest asset of this technique is that the identification of three-dimensional points from the two-dimensional drawings is done by the computer. Thus, the user needs very little knowledge of three-dimensional geometry. The difficulty in this approach is that the orthographic projection drawings, though simplified versions of the real machine, must be drawn very accurately and contain any hidden lines representing desired details. Figure 8 illustrates a shuttle car reconstructed using this technique.

The use of either method results in three-dimensional models that contain errors. Therefore, the user will have the option to go back and adjust the model using an interactive procedure. There is also a library of common shapes and mechanisms that the user may insert into the model wherever needed. For example, a common seat design need not be digitized repeatedly, but only has to be called up from a file and inserted in the operator station.

On certain analyses, such as the illumination analysis or visibility analysis, or when the user is attempting to reconstruct mobile equipment related accidents, it is necessary to create a mine scene. This is done with a technique similar to that which is used in method 1 of entering mining machine geometries. The user defines the dimensions and orientations of certain standard underground mining structures, such as cribbing sets, pillars, railroads, and stoppings. Crosshairs are used to make it easier for the user to pinpoint the exact locations where objects should go. The mine layout may be modified and used repeatedly for different analyses.

Most of the analysis sections of CAP require a sample population for testing. CAP allows the user to input either the actual external anthropometric measurements for one or more individuals directly, or to generate a sample population from the means, standard deviations, and correlations of a set of anthropometric measurements using statistical methods. This second technique is an adaptation of that used in the crewstation assessment of reach (CAR) program developed by the Boeing Aerospace Corporation for the Naval Air Development Center (*3*). The external measurements for the sample population are transformed into internal link lengths and link circumferences, and are used to create either a link-person or a three-dimensional manikin as shown in figure 9. The external measurements required are presented in figure 10.

Once the necessary data has been entered, the user is free to choose any analysis section desired. At any point the user may go back and modify the mine or machine model or sample population based on the analysis results. The remainder of this paper describes the visibility and illumination analysis sections in brief detail as they are currently implemented.

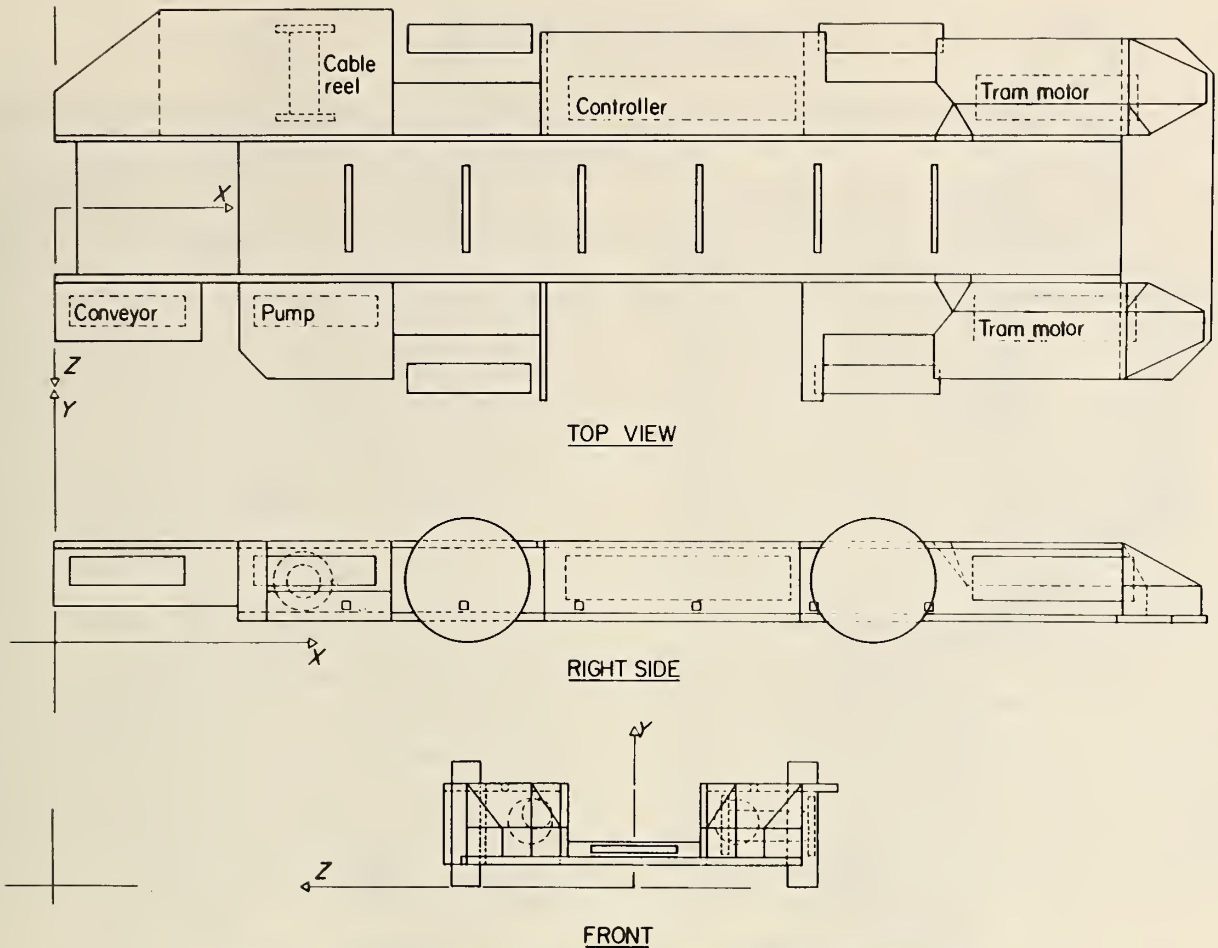

Figure 7.—Typical orthographic projection drawings used for digitization.

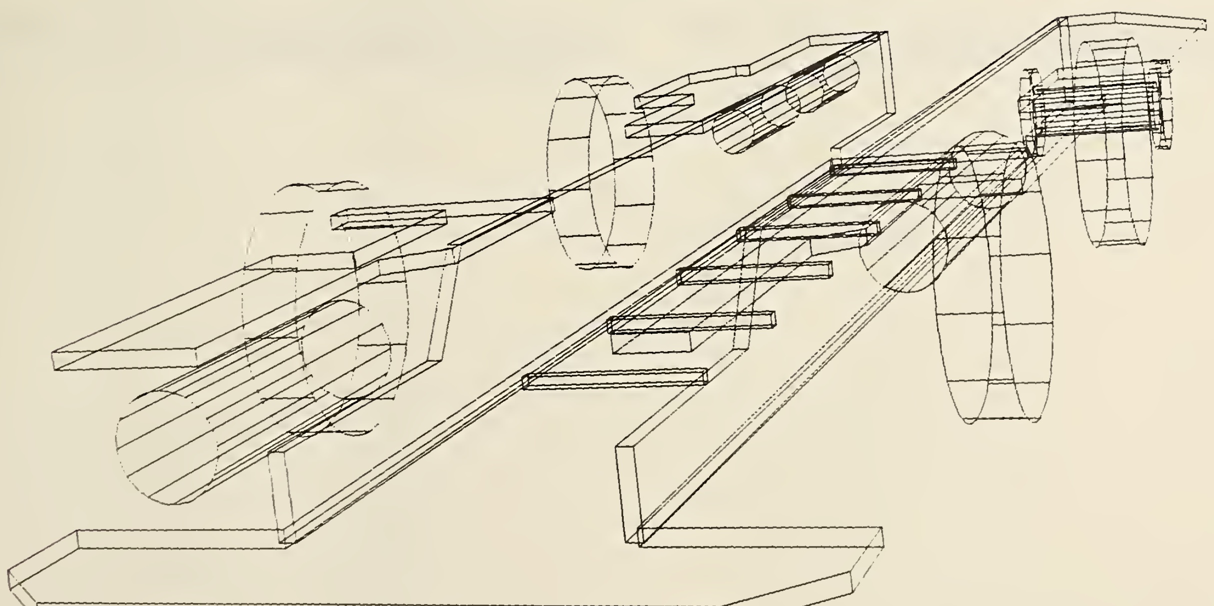

Figure 8.—Three-dimensional reconstruction of a shuttle car using method 2.

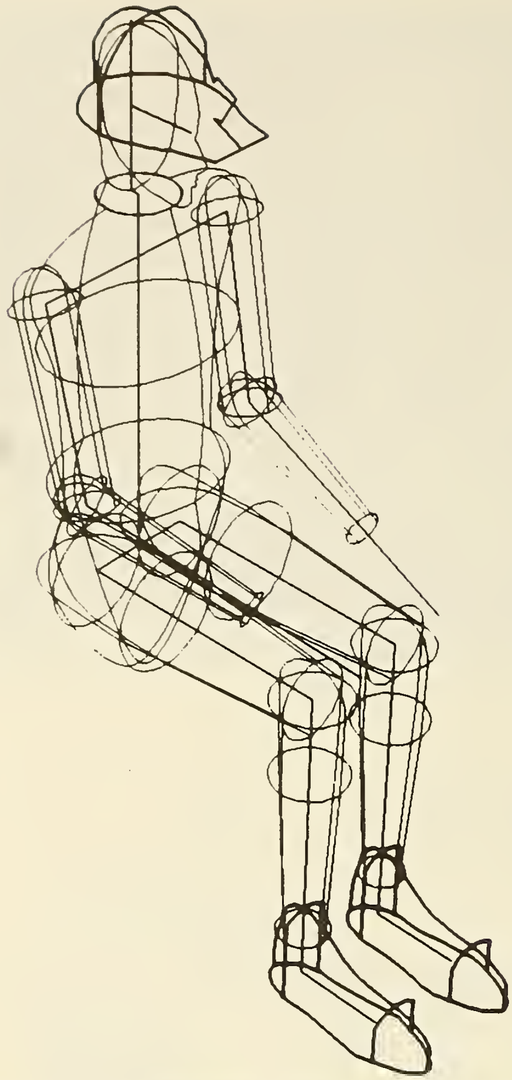

Figure 9.—Three-dimensional manikin used in CAP analysis, equipped with hardhat and miner's boots.

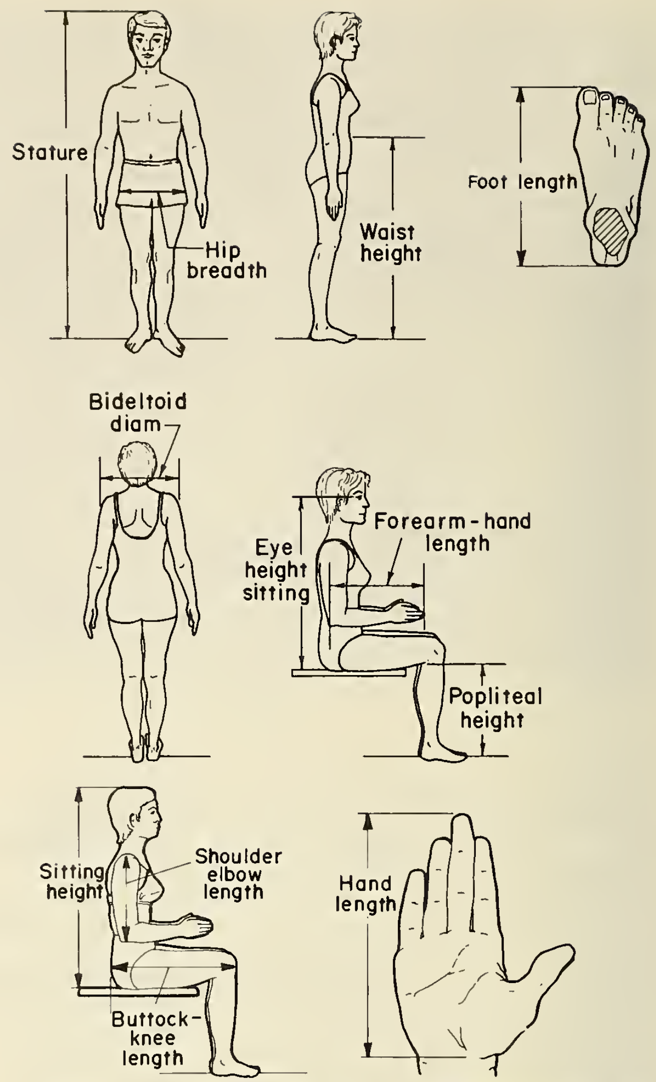

Figure 10.—External anthropometric measurements used to construct the three-dimensional manikin.

VISIBILITY ANALYSIS

In the cramped and dark confines of an underground mine, a machine operator has extensive visibility requirements. It is important to distinguish the *visibility requirements* for a machine, i.e., what needs to be seen, from the *field of visibility,* i.e., what can be seen. The Bureau has sponsored research to determine the visibility requirements of many pieces of underground mining equipment. These visibility requirements are specified by the use of visual attention locations (VAL's) (*4*), and are positioned with reference to machine parts. In this way, the requirements will apply to all the different machine models in an equipment class. For example, operators may be required to see an object at ground level a minimum distance in front of the machine in order to stop before reaching it. This point, or VAL, can be located in space as follows:

Fore-Aft: Front edge of machine and necessary stopping distance.

Lateral: Machine centerline.

Vertical: Floor.

This requirement would not change if the length, width, or height of the machine changed, or if the operator's eye position changed. Thus, the requirements are applicable to all equipment in a given class, i.e., all continuous miners, all shuttle cars, etc. Table 2 contains the coordinates (fore-aft, lateral, and vertical) for each of 54 recommended visual attention locations associated with operation of shuttle cars. The table is grouped into 20 fore-aft, lateral positions, at which from one to four vertical heights are indicated. Figure 11 presents a schematic illustrating these 20 positions. At each position in figure 11 are numbers that correspond to the recommended VAL's in table 2. In the case of shuttle cars, these 54 requirements apply to both directions of travel.

CAP allows the user to create an operator's eye view of the surrounding environment for an assessment of the visibility of VAL's. The users may place their "eye" position and orientate their lines of sight in any way that conforms to the anchor point of the three-dimensional manikin and the acceptable limits of motion of the human body. The view from the operator's station is drawn, taking into account the field of vision at the eye, and the user then notes which VAL's can be seen and what modifications may be needed in the machine design. The analysis is performed repetitively, with the user making judgments as to where the three-dimensional manikin should "look." Figure 12 illustrates several views from the cab of a shuttle car, and figure 13 presents an overall view of the VAL's around the shuttle car.

An optional visibility analysis procedure now being worked on is basically a computer simulation of the experiments described by Canyon Research (*4*). CAP is used to generate either (1) a range of eye locations for a sample of individuals placed in a common configuration or (2) a range of eye locations for a single representative individual through a series of configurations. For each VAL, the graphics processor is used to determine the portion of the range "seen" from each VAL. If a sample of individuals is used, CAP reports the percentage of operators capable of seeing the VAL; if a single individual is analyzed, CAP reports whether the VAL can be seen or not.

Table 2.—Recommended visual attention locations (VAL's) for shuttle cars

Fore-aft, lateral position	Recommended VAL[1]	Vertical height
1—rear edge, machine centerline	1	Operator eye height.
	2	Highest machine point.
2—operator's head, machine centerline	3	Operator eye height.
	4	Highest machine point.
3—operator's head, widest machine point[2] plus 3 ft	5	Operator eye height.
4—front edge plus 2 ft, widest machine point[2] plus half NSD	6	Floor.
	7	Highest machine point.
5—front edge plus 2 ft, widest machine point[2] plus 3 ft	8	Floor.
	9	Median machine height.
	10	Operator eye height.
	11	Highest machine point.
6—front edge, machine centerline	12	Median machine point.
	13	Operator eye height.
	14	Highest machine point.
	15	Seam height.
7—front edge plus 2 ft, widest machine point[3] plus 2 ft	16	Floor.
	17	Median machine height.
	18	Highest machine point.
8—front edge plus 2 ft, widest machine point[3] plus half NSD	19	Floor.
	20	Median machine height.
	21	Operator eye height.
	22	Highest machine point.
9—front edge plus half NSD, widest machine point[3] plus half NSD	23	Floor.
	24	Operator eye height.
	25	Highest machine point.
10—front edge plus half NSD, widest machine point[3] plus 2 ft	26	Floor.
	27	Highest machine point.
11—front edge plus half NSD, machine centerline	28	Median machine height.
	29	Seam height.
12—front edge plus half NSD, operator centerline	30	Floor.
	31	Seam height.
13—front edge plus half NSD, widest machine point[2] plus 3 ft	32	Floor.
	33	Median machine height.
	34	Highest machine point.
14—front edge plus half NSD, widest machine point[2] plus half NSD	35	Floor.
	36	Highest machine point.
15—front end plus NSD, widest machine point[2] plus half NSD	37	Floor.
	38	Operator eye height.
	39	Highest machine point.
16—front edge plus NSD, widest machine point[2] plus 2 ft	40	Floor.
	41	Operator eye height.
	42	Highest machine point.
17—front edge plus NSD, operator centerline	43	Median machine height.
	44	Highest machine point.
18—front edge plus NSD, machine centerline	45	Floor.
	46	Median machine height.
	47	Operator eye height.
	48	Highest machine point.
19—front edge plus NSD, widest machine point[3]	49	Floor.
	50	Operator eye height.
	51	Highest machine point.
20—front edge plus NSD, widest machine point[3] plus half NSD	52	Floor.
	53	Operator eye height.
	54	Highest machine point.

NSD Necessary stopping distance. [1]See figure 11. [2]Same side as operator. [3]Opposite side of operator.

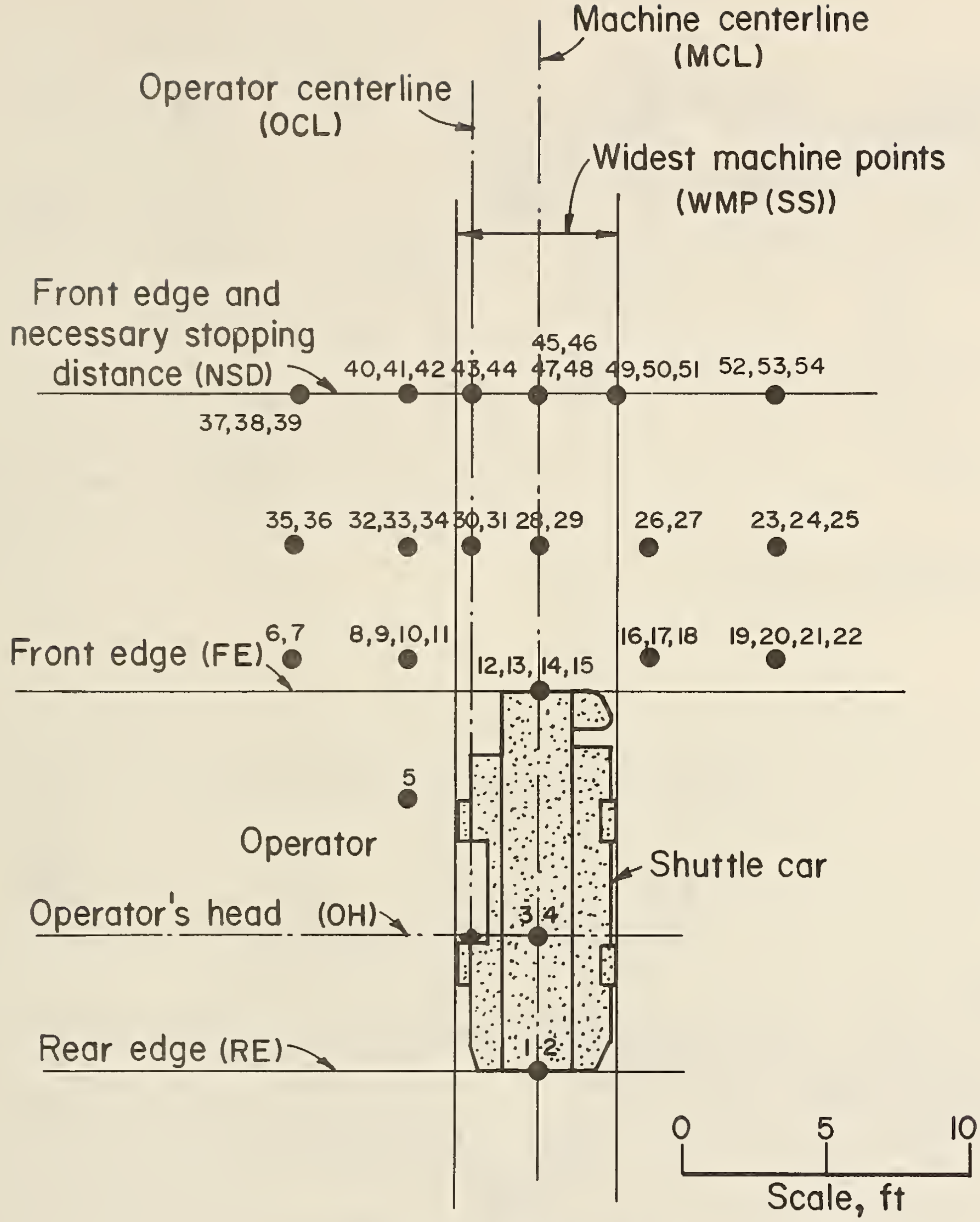

Figure 11.—VAL's for a shuttle car.

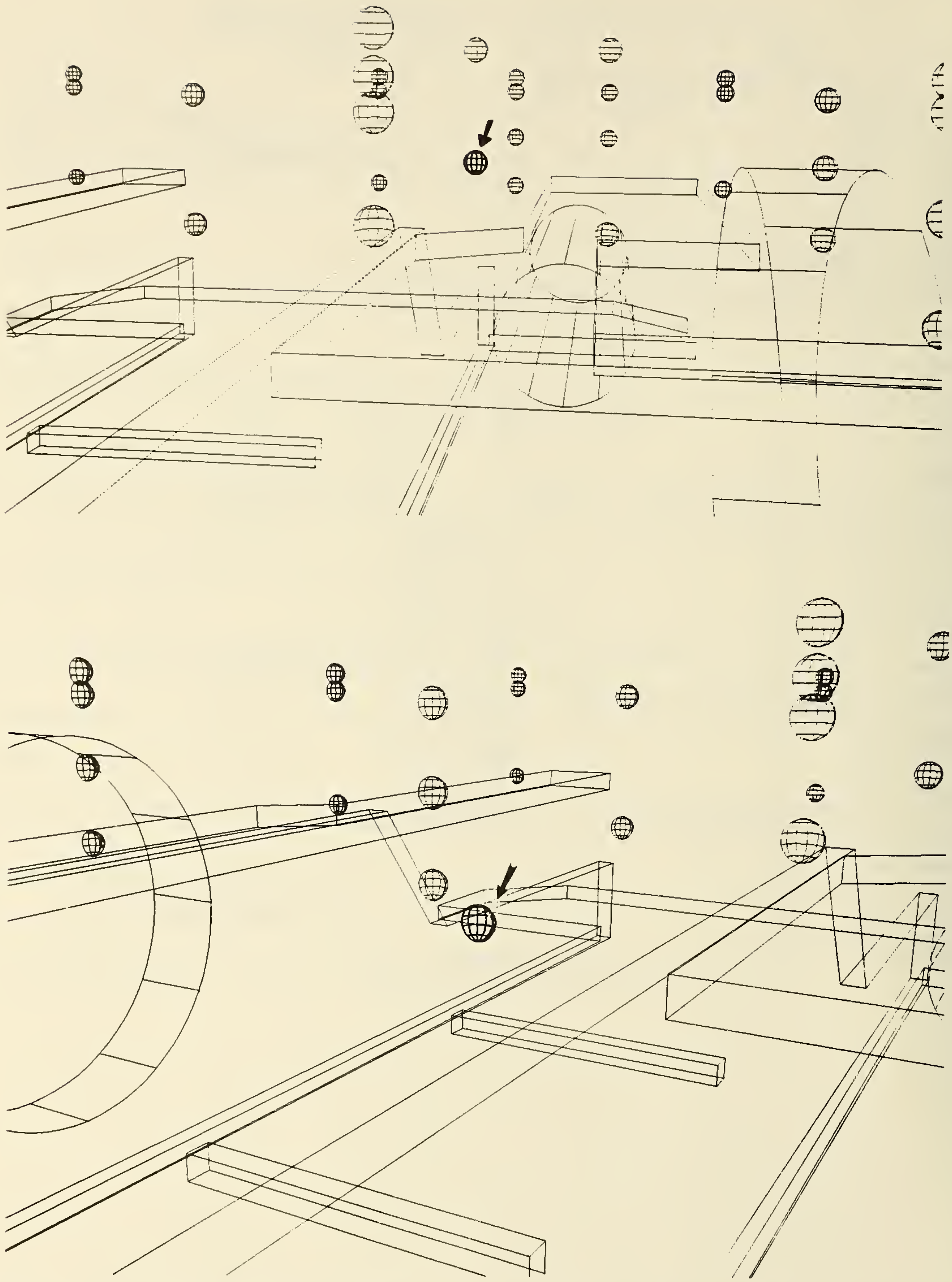

Figure 12.—Operator's eye view of VAL's from a shuttle car cab. Top, view from cab looking at VAL 28 (fig. 11—front edge plus half necessary stopping distance, machine centerline, median machine height); bottom, view from cab looking at the front lower left corner of machine.

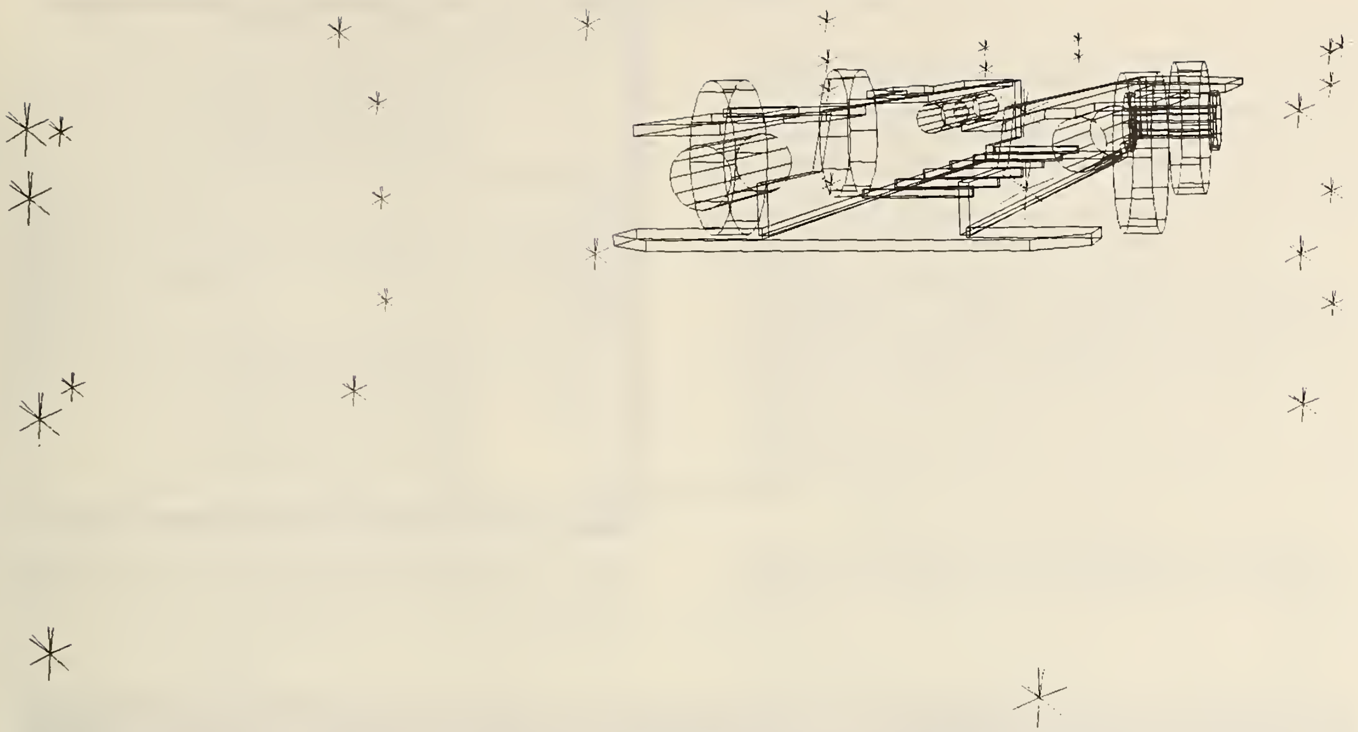

Figure 13.—Overall view of VAL's around a shuttle car.

ILLUMINATION ANALYSIS

The purpose of this section of the CAP model is to provide mining equipment manufacturers, mine operators, and the Mine Safety and Health Administration (MSHA) with a computerized method of evaluating mine illumination systems. This would allow these parties to quickly analyze proposed lighting configurations without resorting to the time-consuming method of building physical mockups and taking light reading manually.

Title 30 of the Code of Federal Regulations requires that designated surfaces within a miner's normal field of vision be illuminated to 0.06 fL while self-propelled mining equipment is being operated in the working place. Different types of machines have different required areas of illumination. For example, for continuous miners, the following areas must be illuminated to 0.06 fL as shown in figure 14:

1. The face.
2. The ribs, roof, floor, and exposed surfaces of mining equipment, from the face to the outby end of the machine's bumper when shuttle car haulage is used or to the first transfer point when continuous conveyor haulage is used.

In addition, the regulations require that light fixtures be designed *and installed* to minimize glare. Glare is a visual sensation that can result in annoyance, discomfort, loss of visual performance, or a reduction of visibility (*5*). Glare is a very significant factor in the design of underground coal mine illumination systems and it may significantly distract from the benefits of these systems. It is prevalent in the underground mine environment because luminaires must often be located close to the mine worker's line of sight, and they are viewed against a very dark background, which results in a high contrast between the light source and its surroundings as shown in figure 15.

CAP will be able to analyze two types of glare, disability glare and discomfort glare. Disability glare is defined as glare resulting in reduced visual performance and visibility. It is caused by stray light, which enters the eye and scatters within, causing a "veiling luminance" over the retina, which in turn, has the effect of reducing the perceived contrast of objects being viewed. Discomfort glare is a sensation of annoyance or, in extreme cases, pain caused by high or nonuniform distribution of brightness in the field of view.

Bureau research has developed methods of quantifying both types of glare for an underground environment. These methods were originally intended to be used for manual calculation, but have been adapted for use by the computer. Using the three-dimensional machine model generated by CAP, the user can use either graphical or numerical input to position and orientate specific luminaires on the machine. The user then specifies the location and field of vision of any observers around the machine. Finally, the areas required to be illuminated, as specified by MSHA, are input.

The analysis routines are then entered to complete the procedure. The routines perform the following functions:

1. Processes the machine model.
2. Checks the specifications on the types and locations of illumination sources entered by the user.

3. Checks the locations of the observers specified by the user.

4. Traces simulated light rays from source locations to an array of measurement points (the ribs, floor, and roof of the mine as specified by the user).

5. Records the incident illumination levels at each measurement point in an organized, easily interpreted format.

6. Calculates the disability and discomfort glare for each observer for the given field of vision.

The results of the illumunation analysis are given for each mine surface defined by the user. Each surface is divided into a rectangular grid of detector points, 2 ft apart. CAP computes the illumination, in footcandles, incident at each of these grid points. It also determines the average illumination in each 2- by 2-ft square by averaging the four points at the corners of each square. This corresponds to the actual measurement method used by MSHA. Any average value that is below the minimum permissible level is marked on the grid and displayed to the user.

The appendix presents the techniques for solving for the illumination at a given point in relation to a mining machine.

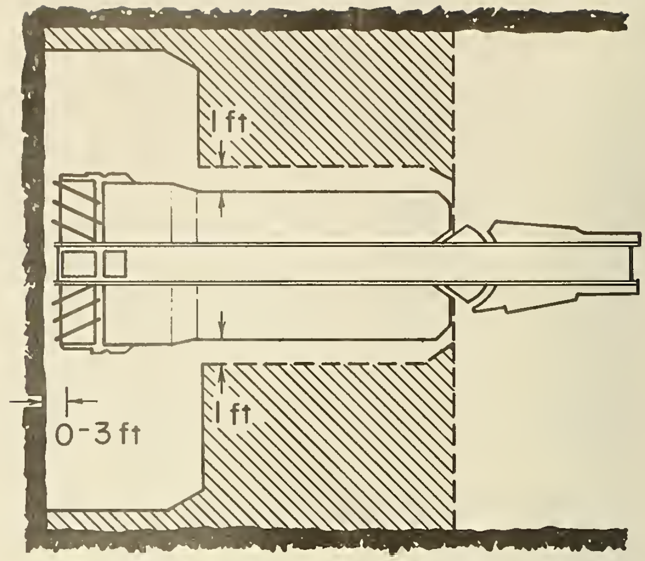

Figure 14.—Area required to be illuminated for continuous mining machines.

Figure 15.—Glare can be a severe problem in underground environments.

CONCLUSIONS

The CAP program can be used by mining machine designers and mining companies to—

Refine control locations to achieve maximum accommodation for an operator sample.

Maximize the visibility of machine operators and assess the ability to see the visual attention locations of mining machinery.

Analyze the effects of discomfort and disability glare and compute the illuminance values for machine-mounted illumination systems on underground coal mining machinery.

Conduct structural analyses of the protective canopies used to protect equipment operators from roof falls.

Widespread use of this program by the mining industry should have a positive impact on the design of new mining equipment and the retrofitting of older equipment. Better human engineering in mining equipment is essential if productivity is to improve along with a reduction in the number of injuries. Ongoing work on CAP includes the development of routines to perform fatigue ratings and timing-of-movements analyses for operator stations based on the machine geometries defined by the user.

CAP will be available for restricted distribution to interested mining machine manufacturers and mining companies in the fall of 1987, and reports on work done to validate the model's results will be published.

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3. Harris, R.M., J. Pennett, and L. Dow. CAR II—A Revised Model for Crewstation Assessment of Reach (contract N62269-79-C-0235, Boeing Aerospace). Naval Air Development Center, June 1980.

4. Sanders, M.S. Visual Attention Locations for Operating Continuous Miners, Shuttle Cars, and Scoops: A Summary (contract J0387213, Canyon Res.). BuMines OFR 29(2)-82, 1981, 67 pp.; NTIS PB 82-187949.

5. Lewis, W.E. (comp.). Underground Coal Mine Lighting Handbook. (In Two Parts.) 1. Background. BuMines IC 9073, 1986, 42 pp.

APPENDIX

In calculating illuminance values, the computer program simulates the method of measurement of illuminance used by MSHA when approving illumination systems by the Statement of Test and Evaluation (STE) approach. In this method, the illuminance at any point on the floor, roof, or ribs is defined as the peak illuminance impinging on that point. Peak illuminance is defined as the maximum footcandle reading obtained from a photometer that is orientated in the direction of maximum illuminance as shown in figure A-1.

For clarity, it should be noted that to convert this computed value of illuminance (footcandles) to luminance (footlamberts), the cosine law must be applied as follows:

$$E_{\text{mine surface}} = E_{\text{peak}} \times (\cos \Theta),$$

and the luminance is

$$L = (Z_r)\, E_{\text{mine surface}},$$

where Z_r is the mine surface reflectivity and L is the value of surface luminance, in footlamberts.

For field-approved illumination systems, L is the value measured by MSHA. For STE-approved illumination systems, E_{peak} is the measured value.

In the case of multiple luminaires, the peak illuminance is defined as the vector sum of the peak illuminances impinging on the point in question as illustrated in figure A-2. Computation of luminance to simulate the MSHA field-approved method is not addressed with this computer program.

The basic equation for calculating the illumination at any point around the machine model is

$$E = I/D^2,$$

where E = illuminance, footcandles,
I = intensity of the light along the vector between the light sources and the point where the light is being measured, candles,
and D = distance between the light source and the point, feet.

There are two other variables that must be taken into account when performing illumination calculations. One is the effect of objects in the path of the light source (shadowing). The second is the location of the measurement point. The effects of shadowing will be discussed first.

Assuming that the measurement point is known, the illumination at that point is given by the equation

$$E = \frac{\vec{I_1}}{D_1^2} + \frac{\vec{I_2}}{D_2^2} + \ldots . \frac{\vec{I_n}}{D_n^2} \text{ (vector summation),}$$

where n is the number of illuminaires.

In other words, the illumination at a specific point is the vector sum total of the illumination from all lamps contributing light to that point. The light is considered to be a vector originating at the lamp (defined as a point source) and ending at the measurement point. If the light vector intersects a plane of the machine model before reaching the measurement point, the effects of that light are canceled out of the illumination equation. Because the three-dimensional machine model is already stored in the computer's memory, the program is able to calculate the intersections of light vectors as they travel to various measurement points. When an intersection occurs, the contributions of that light to the illumination at that measurement point is set to zero.

The determination of measurement points, i.e., those points where the computed incident light measured must be at least 2 fc, is directed by MSHA regulations. MSHA requires that incident light measurements must be taken for each 2- by 2-ft area on the surfaces surrounding the machine that have to be illuminated, as specified in the Code of Federal Regulations. However, there is nothing in the regulations that dictates where the 2- by 2-ft areas are to originate. Thus, the computer divides the areas surrounding the machine (floor, roof, and ribs) into a rectangular grid of measurement points 2 ft apart. The program then computes the illumination, in footcandles, incident at each of these measurement points. It also determines the average illumination in each 2- by 2-ft grid square, by averaging the four points at the corners of the square. Grid squares with an average value below the minimum permissible level are shaded when presented in the output.

The user is given the option of shifting the grid squares up to 2 ft in either the horizontal or vertical direction. This results in a new set of illumination values for that surface. This shifting of the grid squares can mean the difference between compliance and noncompliance on a particular surface. The following section presents the technique used to calculate the illumination values from a typical mining machine headlamp.

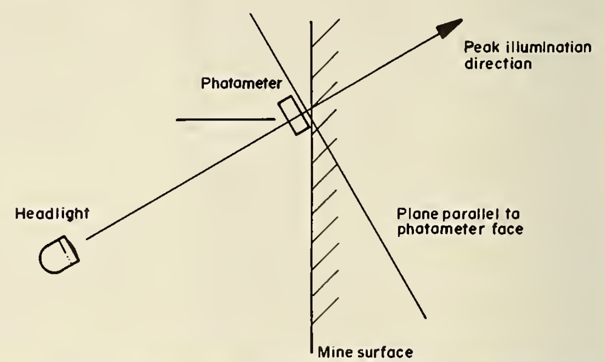

Figure A-1.—Illustration of peak illuminance measurement.

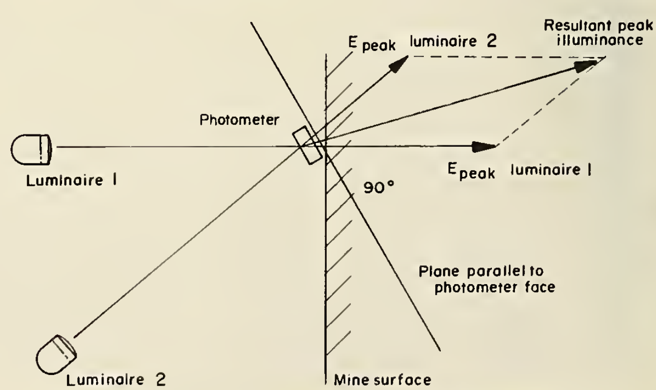

Figure A-2.—Vector addition of illuminances.

ILLUMINATION CALCULATIONS—HEADLAMPS

The following is an example of the equations used for computing the illuminance at a single selected location for a headlamp type luminaire. The same technique is used in the computer model.

Definitions:

The isofootcandle profile of a headlamp is defined and modeled as an ellipse of revolution as depicted at the dotted ellipse as shown in figure A-3.

Origin, O, is defined as the center of the lens face of the headlamp. This point corresponds to the x,y,z location of the luminaire when it was positioned on the machine model. For this example O is set at (O,O,O) as shown in figure A-3.

Measurement point, P, is defined as the location in the x,y,z field where illuminance is to be computed. (P_x, P_y, P_z) are the coordinates of point P.

Θ is defined as the angle between the line $\overline{OP}$ and the y-axis in the plane defined by the origin, O, point P, and the y-axis. Θ is measured in degrees.

P_i is defined as the intersection of the line $\overline{OP}$ and the surface of the eclipse of revolution. Typically, the isofootcandle profile will be a 2.0-fc profile for mine luminaires, from which other field illuminance values can be derived using the inverse square law.

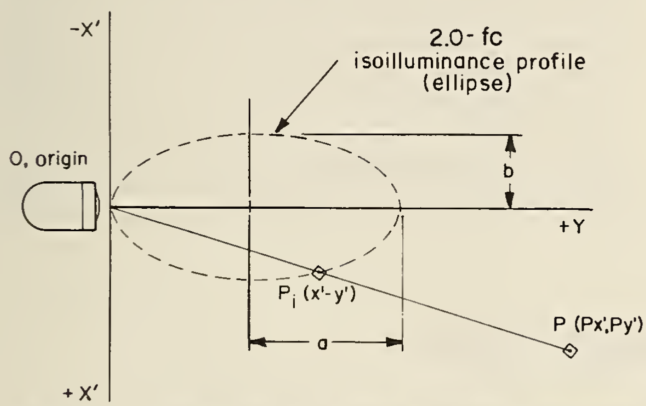

Figure A-3.—Isoilluminance profile model for headlamps: ellipse model.

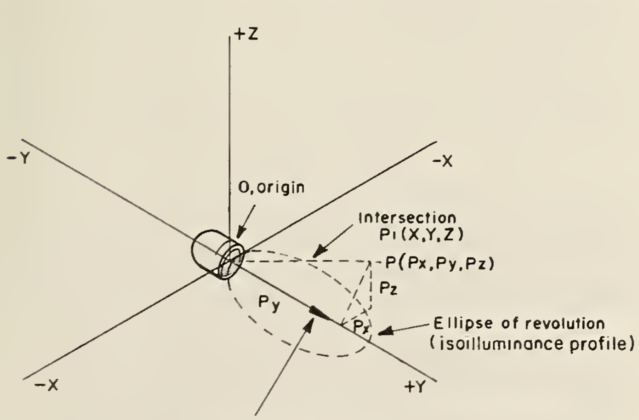

Figure A-4.—Isoilluminance profile model for headlamps: definition of (X', Y') coordinate system.

Figure A-4 is the plane defined by the origin, O, point P, and the y-axis from figure A-3.

The y-axis is defined as the axis of the primary beam (AIM vector) emitted from the headlamp as depicted in figure A-3.

The isofootcandle profile of a headlamp is defined as an ellipse having a major axis, a, and a minor axis, b. The ellipse is tangent to the origin of the (x',y') coordinate system as shown in figure A-4. The full profile is an ellipse of revolution about the y' (also y) axis.

P_i' is defined as the intersection of the 2.0-fc profile and a line joining the origin and point P'.

Illuminance as measured by the MSHA STE method is defined as the footcandles impinging on a surface normal to the line $\overline{OP}$. Note, therefore, that the cosine law of illumination is not used.

The steps for computing the illuminance at point P are

Step 1. Solve for Θ

Step 2. Solve for $P_i' = (P_x', P_y')$ by solving for the intersection of the 2.0-fc profile and the line $\overline{OP}'$.

Step 3. Solve for the length of line $\overline{OP_i}'$, in feet.

Step 4. Using the inverse square law for illumination, solve for illuminance at P, which is the illuminance at point P in figure A-4.

Some of the derivations for the following equations have been omitted.

Step 1. Solve for Θ:

$$\operatorname{Tan} \Theta = \frac{[(P_x)^2 + (P_z)^2]^{1/2}}{(P_y)}$$

$$\Theta = \tan^{-1}\left[\frac{[(P_x)^2 + (P_z)^2]^{1/2}}{(P_y)}\right]$$

Step 2. Solve for $P_i = (P_x', P_y')$:

$$x' = x' \text{ coordinate of point } P_i' = \frac{2ab^2}{b^2 + (P_y'/P_x')^2 a^2}$$

$$y' = y' \text{ coordinate of point } P_i' = (P_y'/P_x')\, x'$$

Step 3. Solve for the length of line $\overline{OP_i}$, in feet:

$$\overline{OP_i} = (x^2 + y^2 + z^2)^{1/2}$$

$$\overline{OP_i} = [(x')^2 + (y')^2]^{1/2}$$

$$\overline{OP_i} = \left[\left[\frac{2ab^2}{b^2 + (P_y'/P_x')^2 a^2}\right]^2 + P_y'/P_x' \left[\frac{2ab^2}{b^2 + (P_y'/P_x')^2 a^2}\right]^2\right]^{1/2}$$

$$\frac{P_y'}{P_x'} = \frac{[(P_z)^2 + (P_x)^2]^{1/2}}{P_y} = \tan\Theta;$$

therefore,

$$\overline{OP_i} = \left[\left[\frac{2ab^2}{b^2 + a^2\tan^2\Theta}\right]^2 + \left[\frac{2ab^2\tan\Theta}{b^2 + a^2\tan^2\Theta}\right]^2\right]^{1/2}$$

or

$$\overline{OP_i} = \left[\left[\frac{2ab^2}{b^2 + a^2 \tan^2 \Theta} \right]^2 (1 + \tan^2 \Theta) \right]^{1/2},$$

where

$$\tan \Theta = \frac{[(P_z)^2 + (P_x)^2]^{1/2}}{P_y}.$$

Step 4. Solve for the illuminance at P:

$E = I/D^2$

Let $D = \overline{OP_i}$ and $E_2 = 2.0$ fc.

$I = E_2 D^2 = E_2(\overline{OP_i})^2$;

therefore,

$I = 2(\overline{OP_i})^2$

where I = beam intensity (luminous intensity) where the isofootcandle profile (2.0 fc) is given as an ellipse.

Therefore, let E = illuminance at any field location P, as shown in figure A-4.

By the inverse square law

$E(P_x,P_y,P_z) = 2(\overline{OP_i})^2/(\overline{OP})^2$ = illuminance at any location (P_x,P_y,P_z) in coordinate system as shown in figure A-4,

where

$\overline{OP} = [(P_x)^2 + (P_y)^2 + (P_z)^2]^{1/2}$,

$$OP_i = \left[\left[\frac{2ab^2}{b^2 + a^2 \tan^2 \Theta} \right]^2 (1 + \tan^2 \Theta) \right]^{1/2},$$

$$\tan \Theta = \frac{[(P_z)^2 + (P_x)^2]^{1/2}}{P_y}.$$

MAINTAINABILITY DESIGN OF MOBILE UNDERGROUND MINING EQUIPMENT

By Ernest J. Conway[1] and Richard L. Unger[2]

ABSTRACT

The Bureau of Mines has initiated a project to investigate the extent to which maintainability design principles are used in the underground mining industry. This paper presents some of the preliminary findings from that work.

INTRODUCTION

Because of the persistently high number of maintenance-related injuries, new methods for reducing injuries and costs are being sought. One factor that contributes directly to injuries and costs is the design of the equipment itself. Cost-effective and safe maintenance can be achieved through improved equipment design for maintenance.

To specifically address the design of underground mining equipment with respect to maintainability, the Bureau has entered into contract J0145034 with Vreuls Research, Inc. The project is organized into two phases. Phase I tasks include a review of relevant maintainability design literature, analysis of maintenance-related accident data, field reviews of equipment design in underground operating environments, and interviews with mine maintenance personnel and equipment manufacturers.

A draft maintainability design guideline is being prepared based upon the findings of these tasks. Phase II tasks will focus on the field validation and revision of the design guidelines. This paper reviews the preliminary findings derived from phase I activities.

PHASE I PRELIMINARY FINDINGS

A review of the maintainability literature produced few specific guidelines that could be applied to underground mining equipment. However, a number of general engineering and human factors design recommendations were found. Where practical, these findings were extrapolated for use in the underground environment (e.g., anthropometric measurements, reach envelopes, access opening sizes, etc.). Several design principles were found that may also be applicable. The plethora of maintainability models, however, appear to be of little practical value.

Analysis of the injury data for underground mines indicates that maintenance-related accidents accounted for approximately 34 pct of *all* lost-time injuries (Mine Safety and Health Administration data). Approximately 29 pct of these injuries can be classified as serious, and they resulted in more than 1 day of lost time.

Table 1 identifies types of serious (days lost >1) maintenance-related injuries for two of the larger mines visited as part of this project. Overexertion and other injuries related to accessing, handling, installing, and removing machine components account for a majority of the reported injuries. Followup reviews of mining equipment at these sites suggested that many of these injuries were the direct result of current equipment design.

Table 1.—Summary of serious (days lost >1) maintenance-related injuries for two mines

Nature of injury	Share of serious lost time injuries, pct
Overexertion and strains while removing, replacing, or manipulating components	36.4
Crushing, pinching, or laceration received while handling machine components	32.4
Impacted by handtools or power tools or other metal parts during maintenance operation	11.5
Lacerations and abrasions while working on equipment	7.1
Slips and falls while working on or around equipment	5.4
Other types of injuries	7.2

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[2]Civil engineer, Bureau of Mines, Pittsburgh Research Center, Pittsburgh, PA.

As expected, the data also revealed that a majority of the accidents resulted in less than 1 day of lost time. The injuries from these accidents included abrasions, contusions, sprains, burns, punctures, and similar types of trauma. In most of these cases, the mine personnel were returned to their jobs or assigned to light duty for a couple of days. These injuries often resulted from equipment design limitations such as limited access opening size, lack of guarding, improper tool design, and poor visibility while performing maintenance tasks. Personnel inattention and inexperience also contributed to these accidents.

A number of crippling injuries and fatalities were also identified to be maintenance related. In several instances, equipment design may have directly or indirectly contributed to these incidents. For example, one mine maintenance man was severely burned when he removed the cover to a power panel and proceeded to reattach a loose wire without first turning off the electric power to the box. An interlock switch on this panel cover might have prevented this accident.

Field inspection of mining equipment revealed a number of maintainability design problems and design limitations that were common to most categories of mobile equipment. Representative maintainability design problems include

Lack of ability to visually inspect components for damage, leaks, or failures (fig. 1).

Inadequate access opening size, preventing personnel from performing tasks with both hands or required tools, or preventing visual inspection of tasks being performed (fig. 2).

Inadequate or no access openings for routinely performed inspections or maintenance actions.

Need to remove or replace nonaffected components in order to access components actually being serviced (fig. 3).

Lack of ability to secure, attach to, or lift heavy components during removal and replacement (fig. 4).

Poor routing of hydraulic lines, water hoses, and power cables on the machine (fig. 5).

Mounting of frequently serviced components in inaccessible locations (fig. 6).

Lack of check valves, stops, and other safety devices for servicing booms, heads, and other hydraulically activated systems.

Design of components and maintenance procedures that require specialized tools and equipment not frequently found in operating mine sections.

Failure to guard exposed components, hoses, valves, lights, and other high-maintenance items on equipment.

Design of equipment bays and cavities that permit accumulation of mud, coal, and other debris that must be removed before maintenance can be performed (fig. 3).

Interviews with mine management and maintenance personnel substantiate these findings. The consensus of the personnel interviewed was that the time required to perform a specific maintenance task could be substantially reduced if simple maintainability design principles were to be applied to the design of mining equipment. In fact, personnel of 8 of the 10 mines visited during phase I reported that they have modified their equipment in order to improve maintainability. Inspection of the mining equipment itself revealed that at all 10 sites equipment had been modified in order to facilitate maintenance.

A review of maintenance records substantiated the consensus. Maintenance data at one well documented mine maintenance operation revealed that 25 pct of all maintenance personnel time was spent replacing hydraulic lines, water hoses, and power cables. The average time to remove and replace these items was 2.2 h per item. Examination of the equipment at this mine indicated that this removal-replacement time could be reduced to under 1 h if 25 pct of the hoses and cable fittings could be relocated to permit direct access.

CONCLUSIONS

The evidence collected to date suggests that substantial improvements in maintenance personnel safety and task performance times could be achieved if relatively simple maintainability design principles were to be applied to the design of mining equipment. The objective for the remainder of this project is to prepare a maintainability design guideline to be used by mine personnel and manufacturers.

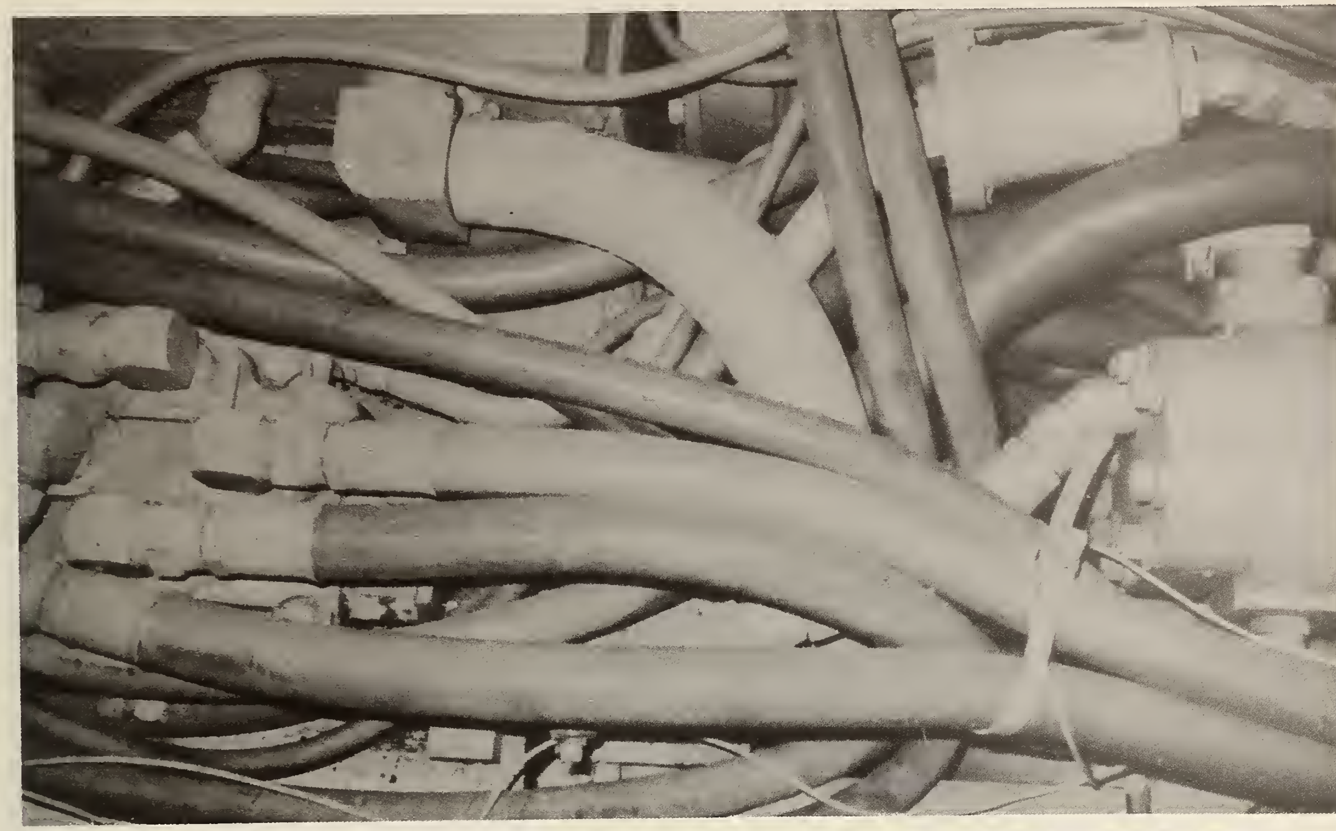

Figure 1.—In this example, many of the hydraulic components cannot be easily inspected for damage or leaks.

Figure 2.—Inadequate access openings prevent visual inspection or the use of proper tools for making repairs.

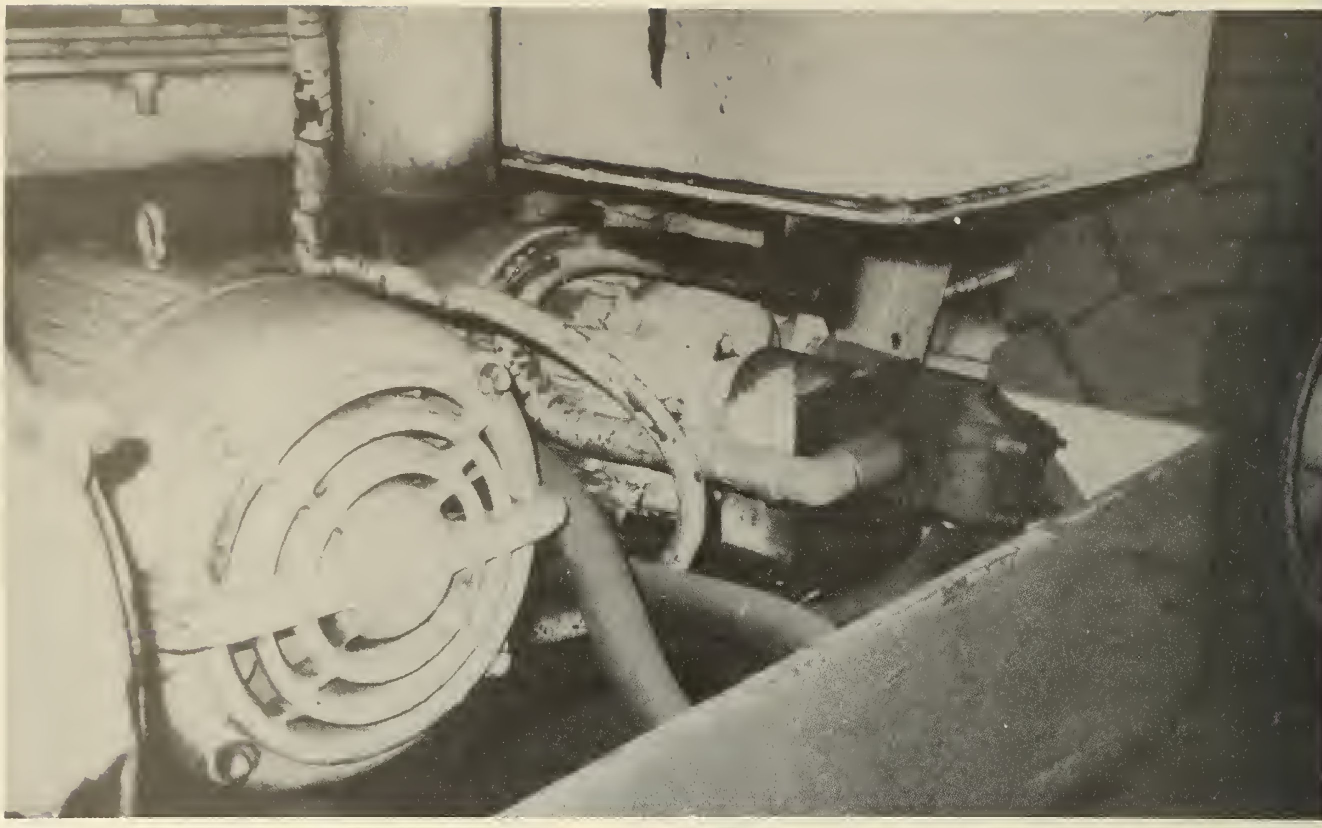

Figure 3.—In order to replace the smaller motor, the larger motor and hydraulic tank must be removed. Also, the design of the trough allows for the accumulation of mud and coal around the components.

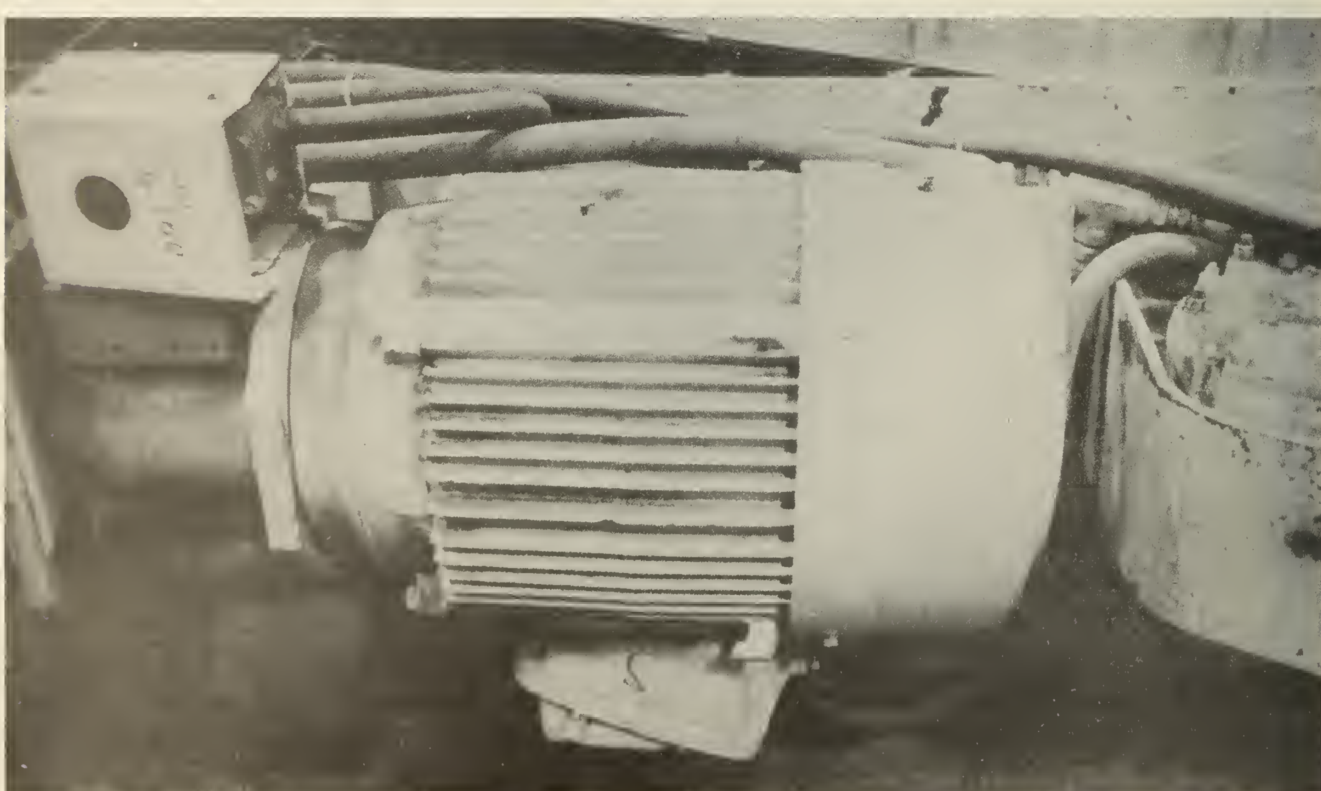

Figure 4.—Massive components, such as this motor, should have designated lift points to facilitate removal and replacement.

Figure 5.—The closely packed routing of hydraulic and electrical lines makes even simple hose repair jobs a major task.

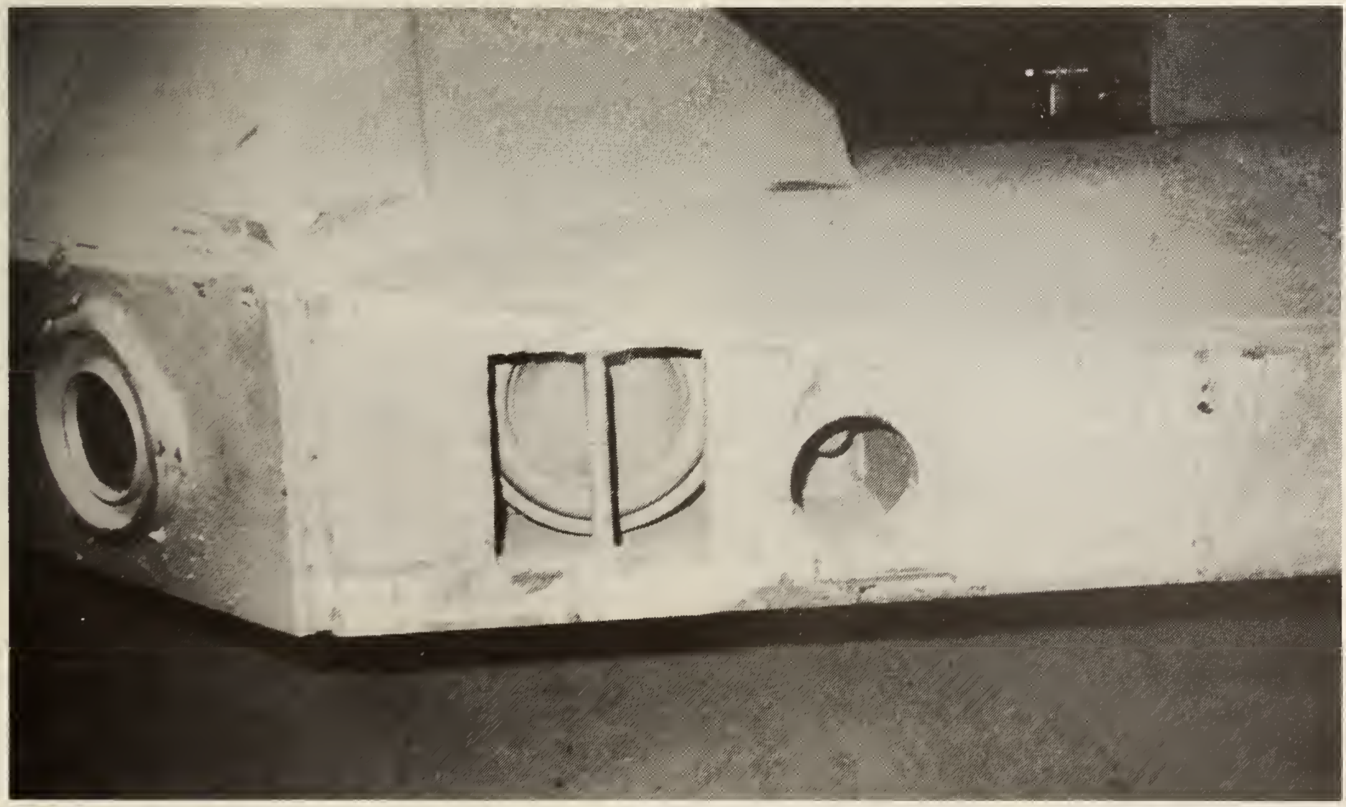

Figure 6.—The simple task of replacing a headlamp can result in extra downtime when headlamps are installed in inaccessible locations.

ASSESSMENT OF ILLUMINATION FOR TASKS PERFORMED BY OPERATORS OF MOBILE SURFACE COAL MINING EQUIPMENT

By Alan G. Mayton[1]

ABSTRACT

This paper presents a portion of the results of an extensive Bureau of Mines study to assess the task illumination needs on mobile surface mining machinery. The intent of the research was to study these needs and the visibility requirements of machinery operators in performing visual tasks. Investigations were performed at 22 surface mining operations, coal and metal-nonmetal, within several mining regions of the United States. Visibility and illumination measurements were taken for 159 visual tasks on 57 surface mining machines including draglines, shovels, blasthole drills, bulldozers, loaders, haul trucks, graders, scrapers, and several service-type vehicles. This paper addresses only the results of investigations at surface coal mines; a subsequent Bureau report will present the overall results and recommendations of the entire study. Tables are presented that compare computed levels of luminance and illuminance for workers in the 25- and 50-yr-age groups. These tables show that illumination, and consequently, task visibility, could be improved. The paper also makes recommendations for improvements in illumination and/or task visibility.

INTRODUCTION

Since the Coal Mine Health and Safety Act became effective in 1969, the Bureau has had a major role in illumination research and in the development of illumination criteria and technology to provide adequate lighting for workers in U.S. mining operations. This has been accomplished most notably in underground coal mining, and to an extent, in surface mining.

In 1977, the Mining Enforcement and Safety Administration (MESA) under the Department of the Interior (now the Mine Safety and Health Administration (MSHA) under the Department of Labor) published proposed mandatory safety standards for the illumination of surface coal mines and surface work areas of underground coal mines (*1*).[2] These standards, however, were never approved. In 1981, the International Commission on Illumination (CIE) began to focus attention on illumination standards for surface mining by establishing a working program for opencast (surface) mine lighting with the objective of developing recommendations for surface mine illumination.

Concurrent with its involvement with the CIE and in view of the unapproved lighting standards, the Bureau initiated a program to study illumination on mobile surface mining equipment from the viewpoint of the equipment operators. The objective of the program was to assess the illumination needs of various surface mining equipment on the basis of the visibility required by workers in performing the necessary visual tasks associated with their jobs. Moreover, the results of this study should provide useful data and information to establish lighting standards for surface mines.

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[2]Italic numbers in parentheses refer to items in the list of references preceding the appendix at the end of this paper.

OVERVIEW AND DESCRIPTION OF WORK

The study was performed in accordance with methods and practices recommended by the CIE and the Illuminating Engineering Society of North America (IES). The approach essentially involved collecting visibility and illumination data through on-site visits to surface mines and quarries in various mining regions of the United States. Investigations took place at 22 different surface mining operations located in Michigan, Indiana, Alabama, Florida, Ohio, Massachusetts, New Hampshire, and New York; 15 were metal-nonmetal (MNM) quarries and 7 were coal mines. The MNM operations included two iron ore mines, four phosphate mines, seven limestone quarries, and two granite quarries. Visual tasks were identified for equipment operators on 57 surface mining machines and quarry equipment including draglines, shovels, blasthole drills, bulldozers, loaders, haul trucks, graders, scrapers, lubrication trucks, fuel trucks, and a water truck. Visibility[3] was measured for 159 tasks with a Blackwell[4] model 5 visual task evaluator (VTE). Existing illumination for each task was determined by using a Minolta 1° luminance meter.

Although the study included both surface coal and MNM mining, this paper will concern only surface coal mining. A subsequent report will address the overall study and will discuss, in detail, the procedures and results.

CIE-IES METHOD

The use of the VTE to obtain visibility measurements is based on the CIE-IES method, which compares an actual, real-world visual task to a standard, visibility reference task. The task consists of an observer viewing a luminous disk whose diameter subtends 4′ of arc at the observer's eyes when presented in a series of 0.2-s exposures on a task background of uniform luminance. Moreover, the visibility reference task is the basis for the visibility reference function, which represents visibility threshold values obtained by a 20- to 30-yr-age reference observer (*2*). A detailed explanation of this method is contained in reference 3.

BLACKWELL MODEL 5 VTE

The Blackwell model 5 VTE operates by allowing one to vary the visual contrast of objects seen through the instrument by fading out the luminance of a scene while at the same time introducing a uniform veiling luminance, or "optical fog." The point at which the critical detail of the task can be seen just barely through the intervening optical fog is called threshold. The proportion of the original contrast perceived through the instrument's optics is called the contrast transmittance (CT) of the instrument. The CT varies from almost 100 pct to almost zero as the background luminance remains nearly constant (*4*).

A measure of how well a given target can be seen is expressed in the amount of reduction in task contrast that is needed to bring the detail to threshold. If, for example, a given target object reaches visibility threshold at a value of CT equal to 0.10, the target is inherently 10 times above its threshold value. The target is said to have a relative visibility level (VL) of 10. A measure of relative visibility for objects is determined mathematically by taking the reciprocal of the contrast transmittance; i.e., VL=1/CT. Thus, scenes that are highly visible will require more contrast reduction to reach visibility threshold, while those that are moderately visible will require less (*4-5*).

Further, measuring task visibility with the VTE requires that the operator of the VTE go through a specific calibration procedure. This procedure is explained in the Bureau report that will present the overall results and recommendations of the study.

FIELD MEASUREMENTS

After selecting a visual task, the VTE was set up in the location from which the operator would normally view the task. The approximate angular position of the VTE and the approximate distance from the outer lens of the VTE to the object or surface of interest were measured or estimated and then recorded. The proper outer lens unit was selected based on the recorded distance and was attached to the front of the VTE. While looking through the VTE, the operator adjusted the contrast control dial on the side of the instrument to threshold contrast no fewer than five times and the readings were recorded. The luminances of the target and its background were then measured with the Minolta meter. The illuminance or illumination of the task was determined from the luminance measured for a reflectance standard, the RS-1 plaque (reflectance approximately 100 pct), which was placed on or directly above the target. In addition, Munsell charts were used where needed to determine the reflectance of surfaces of interest. Slide photographs were also taken of the illuminated equipment and the detail of each task.

The data collected from field measurements were subsequently tabulated, adjusted to take into account the difference in the visual conditions of the model 5 VTE relative to single glimpse conditions used in reference 3, and then analyzed according to the *indirect method* contained in reference 3. Representative results of the data analysis appear in the appendix tables at the end of this paper.

[3]Visibility and illumination data resulting from investigations at the two granite quarries and one limestone quarry were not included because the VTE was later found to be out of calibration. Also, it was not possible to obtain visibility measures at the phosphate mines and one other limestone quarry.

[4]Reference to specific products does not imply endorsement by the Bureau of Mines.

CONCLUSIONS AND RECOMMENDATIONS

This study shows that the type and extent of illumination does vary from mine to mine and seems to be influenced by several factors including mine size, tonnage, and management philosophy. Although the operators of surface mines and quarries, in general, have made positive strides toward providing adequate machine lighting, there are instances where the lighting and/or visibility for certain visual tasks could be improved.

One example involves the power cable on draglines or shovels, which must be handled when relocating these machines. Because the cable is frequently dragged along the ground during these procedures, the cable can become discolored so that it blends with the surface of the ground. The visibility of the power cable in this case could be improved by applying material such as reflective tape to increase the cable's contrast as seen against its background.

Another example is the need for improving visibility and illumination on dozers and loaders in viewing areas immediately ahead of the machines, and areas adjacent to either end of the blade or bucket. Improvements in these areas can be made by (1) assuring the proper aiming of luminaires and/or (2) replacing existing lamps with those of higher intensity.

Two other examples involve machinery working near the highwall of the mining pit. A principal danger associated with the highwall is the potential for rocks and other material to fall or roll off these nearly vertical walls of overburden. The danger in dump areas is the potential for haul trucks to topple over the edge of the pit when dumping waste material. Illumination levels can be increased and the required visibility attained in these cases by using portable light plants. The light plants, however, should be placed in locations that would minimize glare for equipment operators.

Finally, the use and application of the instrumentation and methods presented in this paper may help a surface mining company to improve its existing levels of luminance and illuminance on and immediately about its mining equipment. Further, the tables in the appendix show the results of calculations based on the field data. Because of the wide variation in machine lighting, the limited time available to take measurements on operating equipment, and the limitations of the instruments used, the data given in the tables are only indications of the luminances, illuminances, and reflectance factors needed to perform the various visual tasks.

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APPENDIX.—RESULTS OF TASK VISIBILITY MEASUREMENTS

The tables of data presented should *not* be construed as absolute, but should be used as a general guide to help in better understanding the illumination needs of machinery operators at surface mines. Also, note the following regarding the data:

Values appearing under the column headings "Computed luminance" and "Computed illuminance" were calculated for the median age in each group; i.e., the average 25- and 50-yr-age groups of the normal population.

Computed values of luminance and illuminance were rounded, for consistency, after the calculations were made.

Variations in luminances and illuminances for similar tasks and equipment are largely the result of the wide differences in conditions under which field measurements were taken.

In general, the visual task with high contrast between the task target or critical detail and its background, will result in good visibility and relatively lower illuminance levels; conversely, the visual task with low contrast will result in poorer visibility and relatively higher levels of illuminance.

The footnote "Supplemental lighting" refers to illumination added to the scene for certain visual tasks (generally in the direction of normal or existing lighting) to increase the transmittance through the VTE.

Table A-1.—Illumination values resulting from task visibility measurements for coal mine draglines

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
DRAGLINE 1							
SEEN FROM—							
Operator's cab: Tooth of bucket resting on ground	5.11	100	0.058	0.095	9.00	3.10	5.13
DRAGLINE 2							
SEEN FROM—							
Operator's cab:							
Top of spoil pile	[1]2.40	150	0.036	0.058	2.08	1.74	2.80
Lower edge of bucket on slope of pit	[1]1.38	105	.371	.743	47.10	.79	1.58
Coal with respect to overburden	[1]1.34	150	1.18	2.99	14.18	8.34	21.11
Dump block on hoist rope	[1]2.10	150	.039	.063	2.86	1.36	2.19
Ground level at rear of machine: Power cable	1.31	3.7	2.22	6.86	9.92	22.40	69.17
DRAGLINE 3							
SEEN FROM—							
Operator's cab:							
Control panel button	9.24	1.8	0.037	0.060	34.52	0.11	0.17
Tooth of bucket resting on ground	1.27	24.1	1.121	2.193	18.90	5.94	11.61
Landing: Landing edge to stairs	3.48	4.7	.014	.022	3.45	.41	.61

[1]Extrapolated from other measurements.

Table A-2.—Illumination values resulting from task visibility measurements for coal mine shovels

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
SHOVEL 1							
SEEN FROM—							
Operator's cab: Rear edge of dipper resting on ground	6.84	28	0.381	0.765	16.52	2.31	4.63
SHOVEL 2							
SEEN FROM—							
Operator's cab:							
Rear edge of bulldozer	1.41	50	0.038	0.061	4.26	0.89	1.43
Rock on slope of bench highwall	.70	25	.251	.478	10.00	2.52	4.78
Rear edge of dipper resting on ground	2.00	24.6	.80	.139	10.00	.80	1.39
SHOVEL 3							
SEEN FROM—							
Operator's cab:							
Top rear edge of loaded dipper	[1]1.40	30	0.240	0.453	10.00	2.40	4.53
Top edge of empty truck bed	[1]1.20	20	.062	.103	10.00	.62	1.03
Top edge of truck bed loaded	[1]1.30	25	.513	1.08	34.62	1.48	3.12
Height of load in truck	[1]1.70	30	.045	.074	1.76	2.58	4.20
Ground level at rear of machine: Power cable	.23	3.5	.020	.031	17.39	.12	.63
SHOVEL 4							
SEEN FROM—							
Operator's cab: Top rear edge of loaded dipper	[1]12.60	25	1.30	3.39	10.00	13.06	33.91
SHOVEL 5							
SEEN FROM—							
Ground level at rear of machine:							
Bottom rung of boarding ladder	2.09	2.3	0.140	0.248	12.92	1.08	1.92
Fifth rung of boarding ladder used as handhold	2.83	1.3	.003	.005	.71	.46	.66

[1]Extrapolated from other measurements.

Table A-3.—Illumination values resulting from task visibility measurements for coal mine loaders

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
LOADER 1							
SEEN FROM—							
Ground level at boarding ladder:							
Bottom step	[1]0.78	2.3	0.017	0.026	1.28	1.33	2.06
Handrail	[1].02	1.4	.016	.024	50.00	.03	.05
Plate-metal landing outside operator's cab:							
Handrail	1.01	1.4	.017	.026	1.98	.86	1.33
Edge of landing to descending ladder	.39	3.6	.068	.114	10.26	.66	1.11
Operator's cab: Height of load in bucket	.37	15	.031	.050	10.81	.29	.46
LOADER 2							
SEEN FROM—							
Operator's cab: Left end of bucket	2.65	15	0.028	0.046	1.89	1.51	2.41
LOADER 3							
SEEN FROM—							
Operator's cab: Top rear edge of loaded bucket	8.78	13	0.162	0.294	17.08	0.95	1.72

[1]Extrapolated from other measurements.

Table A-4.—Illumination values resulting from task visibility measurements for coal mine haul trucks

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
TRUCK 1							
SEEN FROM—							
Driver's cab:							
Edge of ditch	0.50	130	0.107	0.186	14.81	0.72	1.25
Pile of debris in front of truck	.54	55	.018	.029	1.85	1.00	1.55
Ground level at boarding ladder:							
Bottom step	[1]1.21	2.2	.018	.028	1.65	1.10	1.71
Handbar	[1].61	1.3	.043	.070	8.20	.53	.85
TRUCK 2							
SEEN FROM—							
Driver's cab: Left curb at dump hopper	1.02	35	0.620	1.37	6.86	9.04	19.97
TRUCK 3							
SEEN FROM—							
Driver's cab:							
Edge of berm at waste dump[2]	0.91	32.5	0.025	0.041	1.10	2.27	3.71
Body-down indicator	[1].31	3	.069	.115	6.45	1.08	1.78
TRUCK 4							
SEEN FROM—							
Landing at head of boarding ladder:							
Handrail of landing	0.10	1.8	0.022	0.035	20.00	0.11	0.18
Edge of landing (descending)	.54	3.6	.016	.026	1.80	.89	1.45
TRUCK 5							
SEEN FROM—							
Driver's cab:[2]							
Tire track at loading shovel[3]	3.15	99.3	0.432	0.886	8.89	4.86	9.97
Sloped waste pile at base of bench highwall[3]	1.48	138	.198	.367	1.35	14.67	27.18
Rear (shadowed) edge of loading shovel[3]	1.90	99.3	.781	1.78	10.00	7.81	17.80

[1]Supplemental lighting required to make measurements. [2]Left, side-view mirror used. [3]Positioning and/or maneuvering mark.

Table A-5.—Illumination values resulting from task visibility measurements for coal mine blasthole drills

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
DRILL 1							
SEEN FROM—							
Operator's cab:							
Shovel (marker) to align machine for drilling next hole	27.24	60	0.226	0.423	16.52	1.37	2.56
Stem lock against drill pipe	15.10	8	.128	.227	4.44	2.89	5.11
Paint mark on hoist chain	16.53	12	.081	.137	15.12	.54	.91
DRILL 2							
SEEN FROM—							
Landing at head of boarding ladder:							
Edge of landing to descending stairs	2.40	3.7	0.063	0.106	4.17	1.52	2.55
DRILL 3							
SEEN FROM—							
Operator's cab: Point of pressure gauge	[1]1.51	1.5	0.012	0.018	56.95	0.02	0.03
DRILL 4							
SEEN FROM—							
Operators cab:							
Edge of box (marker) to align machine for drilling next hole	1.43	21	0.568	1.22	6.99	8.12	17.45
Edge of deck bushing against drill pipe	9.18	4.5	.533	1.13	5.45	9.78	20.71
Rope with weighted end for spacing holes	[1]23.30	20	.336	.663	4.25	7.91	15.61
Ground level at operator's cab: Boarding step	2.16	4.5	.028	.045	4.63	.60	.96
DRILL 5							
SEEN FROM—							
Operator's cab:							
Edge of deck bushing without drill pipe	2.14	6	0.147	0.262	2.34	6.27	11.21
Edge of pipe rack against drill pipe	4.43	6	.091	.156	10.38	.88	1.50
Ground level at boarding stairs:							
Bottom step	4.50	2.1	.032	.051	8.22	.38	.62
Handrail	1.31	1.8	.095	.163	8.40	1.13	1.94
DRILL 6							
SEEN FROM—							
Operator's cab:							
Edge of deck bushing against drill pipe	1.48	5	0.304	0.588	25.00	1.22	2.35
Mark on hoist cable	.93	4.3	.029	.041	13.98	.65	1.00
Drop pin in drill pipe carousel	55	6	.790	1.81	21.82	3.62	8.30
Point of pressure gauge	6	1.4	.616	1.35	62.17	.99	2.17
Small hole in deck	2.85	4	.458	.948	32.28	1.42	2.94

[1]Supplemental lighting required to make measurements.

Table A-6.—Illumination values resulting from task visibility measurements for coal mine explosive trucks

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
TRUCK 1							
SEEN FROM—							
Ground level at rear of truck:							
Edge of bagged explosives	1.84	3	1.04	2.53	29.35	3.54	8.64
Detonating cord against primer	2.30	1.3	.188	.347	27.83	.68	1.25
Hole slot in primer	2.28	1.3	.258	.493	32.46	.79	1.52
Black digit on tape measure	20.70	4.3	.718	1.62	9.90	7.25	16.37
TRUCK 2							
SEEN FROM—							
Ground level at rear of truck: Edge of blasthole	[1]150	4.5	0.312	0.612	9.93	3.14	6.16

[1]Supplemental lighting required to make measurements.

Table A-7.—Illumination values resulting from task visibility measurements for coal mine scrapers

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
		SCRAPER 1					
SEEN FROM—							
Operator's cab:							
Cutting edge of pan	1.96	16	2.15	6.49	18.88	11.40	34.39
Pothole in road	.77	39.6	.635	1.40	20.78	3.06	6.74
Rock on road	.45	47	1.47	3.97	17.78	8.26	22.32
Top rear edge of loaded pan	[1]8.20	14	.204	.378	9.76	2.09	3.87
Ground level at rear push bumper:							
Boarding step	[2]12.24	2	.012	.019	2.53	.49	.76
Handbar for boarding	[2]1.79	1.3	.776	1.79	14.52	5.34	12.30
		SCRAPER 2					
SEEN FROM—							
Operator's cab: Cutting edge of pan	54.0	19	0.028	0.046	12.52	0.23	0.36

[1]Extrapolated from other measurements. [2]Supplemental lighting required to make measurements.

Table A-8.—Illumination values resulting from task visibility measurements for coal mine bulldozers

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
		BULLDOZER 1					
SEEN FROM—							
Operator's cab:							
Dirt at left blade end	0.80	23	0.054	0.088	1.25	4.32	7.05
Dirt above blade when pushing load	135.70	16	.002	.003	.02	10.00	15.00
		BULLDOZER 2					
SEEN FROM—							
Operator's cab: Dirt at right blade end	1.56	20	0.063	0.014	1.92	3.26	5.43
Ground level:							
Handbar above trunion arm for boarding	.41	1.6	2.96	10.27	34.15	8.65	30.09
Edge of trunion arm step for boarding	.44	1.6	.021	.033	4.54	.46	.72
		BULLDOZER 3					
SEEN FROM—							
Operator's cab: Power cable of dragline	0.47	42.2	0.492	1.03	21.28	5.25	11.00
		BULLDOZER 4					
SEEN FROM—							
Ground level:							
Edge of bottom at boarding ladder	0.06	2.1	0.018	0.028	16.67	0.11	0.17
Handhold (rung)	.03	1.4	.086	.146	100.0	.09	.15
Operator's cab: Top edge of blade against load pushed	42.65	14	.421	.864	4.99	8.43	17.30
		BULLDOZER 5					
SEEN FROM—							
Operator's cab: Left blade end against load pushed	0.86	15	0.325	0.637	30.23	1.08	2.11
		BULLDOZER 6					
SEEN FROM—							
Operator's cab: Left blade end against load pushed	[1]122.40	15.6	0.085	0.145	3.34	2.54	4.34
		BULLDOZER 7					
SEEN FROM—							
Operator's cab: Left blade end against load pushed	[1]12.60	15.3	0.188	0.344	23.81	0.79	1.45
		BULLDOZER 8					
SEEN FROM—							
Ground level at rear of machine:							
Edge of grouzer (step) for boarding	[1]42.20	2.1	0.001	0.002	0.02	5.00	10.00
		BULLDOZER 9					
SEEN FROM—							
Operator's cab:							
Left blade end against muddy load pushed	1.51	17.5	0.035	0.056	4.64	0.76	1.20
		BULLDOZER 10					
SEEN FROM—							
Operator's cab: Top of blade against load pushed	6.35	13.3	0.132	0.234	8.66	1.52	2.70
Ground level at boarding ladder:							
Bottom rung	[1]36.80	2.5	.008	.012	.46	1.78	2.57
Handhold (rung)	1.32	1.3	.057	.093	61.36	.09	.15
		BULLDOZER 11					
SEEN FROM—							
Operator's cab:							
Left blade end against ground surface	1.39	14.8	0.572	1.23	17.27	3.31	7.12
Top, right blade end against ground surface	3.26	14.5	.081	.138	8.28	.98	1.67
Edge of deck outside door of cab	1.33	3.3	.200	.368	32.33	.62	1.14
Ground level:							
Edge of trunion arm (step) for boarding	.39	1.7	.010	.015	2.56	.39	.60
Handbar above trunion arm for boarding	.93	2.8	.005	.007	2.15	.23	.35

[1]Supplemental lighting required to make measurements.

Table A-9.—Illumination values resulting from task visibility measurements for coal mine motor graders

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
GRADER 1							
SEEN FROM—							
Operator's cab:							
Pothole in road	[1]0.31	85	2.57	8.43	29.03	8.84	29.05
Top of windrow at right blade end	1.04	14.6	.106	.184	4.81	2.20	3.82
Top of left blade end	6.26	10.7	.014	.021	.96	1.46	2.16
Rock on road	.44	65	.492	1.03	22.73	2.16	4.53
Clumped dirt at right blade end	1.35	14.7	5.41	25.76	28.15	19.20	91.51
Ground level at boarding ladder:							
Bottom rung	[1].63	1.9	.024	.037	4.76	.50	.78
Handbar	[1].11	1.4	.009	.014	9.09	.10	.15
GRADER 2							
SEEN FROM—							
Operator's cab:							
Left blade end	5.63	13.4	0.014	0.021	1.06	1.30	2.02
Right blade end	7.23	9.4	.123	.216	14.38	.86	1.50
Ground level at boarding ladder: Bottom step	2.74	1.9	.320	.625	5.84	5.48	10.70
GRADER 3							
SEEN FROM—							
Operator's cab:							
Right blade end	2.99	13.3	0.008	0.012	0.67	1.14	1.76
Bottom of left blade end	1.23	8.7	.007	.010	.81	.87	1.23
Top of left blade end	1.23	7.8	.027	.043	7.32	.37	.58
Ground level at boarding ladder: Bottom step	.36	2	.041	.067	22.22	.18	.30
GRADER 4							
SEEN FROM—							
Operator's cab:							
Right blade end	2.26	9	0.012	0.019	1.33	0.94	1.45
Left blade end	2.45	13.4	.080	.135	5.31	1.50	2.54
Ground level at boarding ladder: Bottom step	1.67	1.7	.052	.085	4.19	1.23	2.02

[1]Supplemental lighting required to make measurements.

Table A-10.—Illumination values resulting from task visibility measurements for coal mine fuel trucks

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
TRUCK 1							
SEEN FROM—							
Ground level:							
Black digit of fuel meter	[1]0.58	2.3	0.109	0.190	8.62	1.27	2.20
Boarding step of cab	[1].30	2.7	.038	.061	13.33	.29	.46
Handbar for boarding	[1]1.65	1.3	.026	.041	6.67	.39	.62
Corner of walkway behind driver's cab:							
Edge of walkway along fuel tank	[1].24	4.6	.007	.010	4.17	.17	.25
TRUCK 2							
SEEN FROM—							
Ground level:							
Black digit of fuel meter	[1].70	1.3	0.178	0.325	7.03	2.54	4.63
Nozzle of fuel hose	[1]1.02	1.5	.167	.304	17.65	.95	1.72
Boarding step of cab	[1]1.03	3	.010	.015	.97	1.03	1.59

[1]Supplemental lighting required to make measurements.

Table A-11.—Illumination values resulting from task visibility measurements for coal mine lubrication trucks

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
TRUCK 1							
SEEN FROM—							
Ground level at rear of truck:							
Tool in tool box	[1]1.21	1.3	0.054	0.089	9.09	0.59	0.98
Nozzle of grease hose	[1]12.80	2	.029	.046	9.22	.32	.50
Chain link of boarding step	[1]358	3.5	.064	.108	.22	29.32	49.02
TRUCK 2							
SEEN FROM—							
Ground level at grease fitting of haul truck wheel:							
Nozzle of grease hose	[1]314	2.1	0.040	0.064	6.30	0.63	1.02
TRUCK 3							
SEEN FROM—							
Ground level:							
Nozzle of grease hose	[1]33.2	1.6	0.068	0.114	3.46	1.96	3.28
Boarding step of cab	[1]1.19	2	.022	.035	9.24	.24	.38
Handbar for boarding	[1]1.63	1.5	.004	.006	3.07	.13	.19

[1]Supplemental lighting required to make measurements.

Table A-12.—Illumination values resulting from task visibility measurements for coal mine water truck

	Existing illuminance, fc	Viewing distance, ft	Computed luminance, fL: 20- to 30-yr age	Computed luminance, fL: 40- to 60-yr age	Reflectance, pct	Computed illuminance, fc: 20- to 30-yr age	Computed illuminance, fc: 40- to 60-yr age
SEEN FROM—							
Operator's cab:							
Vertical stream of water at fill-up point	0.94	117	0.103	0.177	5.32	1.93	3.33
Top of berm at right side of road	.69	88	.009	.013	1.45	.61	.92
Water-filled pothole	1.13	110	.104	.181	5.31	1.97	3.40
Rock on road	.64	110	.103	.177	7.81	1.31	2.27
Ground level at boarding ladder:							
Bottom rung	[1]2.04	2.5	.016	.025	.98	1.66	2.57
Handhold (rung)	[1]1.81	1.3	.181	.330	11.05	1.64	2.98

[1]Supplemental lighting required to make measurements.

ANALYSIS OF MAINTENANCE AND REPAIR ACCIDENTS ON HAULAGE TRUCKS

By Thomas J. Albin[1] and Dennis A. Long[2]

ABSTRACT

The Bureau of Mines analyzed metal and nonmetal surface mining maintenance accidents for a selected group of mining machines including haulage trucks, draglines, power shovels, and hydraulic excavators. The overall incidence rate of accidents has declined from 6.91 injury accidents per 200,000 h in 1978 to 4.34 injury accidents per 200,000 h in 1985; however, maintenance accident incidence has remained approximately constant. The severity of these maintenance accidents remains a serious problem, with an average of 189 days lost, including statutory days assessed.

Analysis of accident statistics in the Mine Safety and Health Administration data base shows that the predominant types of injury accidents, in terms of frequency and severity, are caught, hit-by, falls, overexertion, and electric shock.

Further analysis was conducted as to the most hazardous subsystems of haulage trucks. Maintenance accident records involving off-road haulage trucks provided information regarding the particular subsystem worked on at the time of the accident. Maintenance times for haulage trucks, by subsystem, were obtained from a surface iron mine. The incidence rate and severity of accidents on any particular subsystem were then compared to the amount of time spent working on that subsystem relative to the total time spent in maintenance activity.

Statistically, maintenance of the cooling subsystem, suspension, and tires all have accident rates that are significantly greater than accident rates on the other truck subsystem.

INTRODUCTION

Maintenance and repair accidents have been identified as a matter of serious concern to the surface mining industry (*1*).[3] This paper presents a condensed, preliminary analysis of mobile equipment maintenance and repair injuries and discusses injury prevention in the surface metal and nonmetal mining industry.

The principal source of accident data used in this paper is the mine accident data file maintained by the Mine Safety and Health Administration (MSHA) at its Denver Safety and Health Technology Center. The data were utilized with the aid of the Bureau's accident data analysis (ADA) program. It is important to note that this program (*2*) defines an accident as "any unforeseen or uncontrolled occurrence which shuts down a face or work area for 30 minutes or more, whether or not an injury was sustained." A reportable injury is defined by MSHA (*3*) as an "injury to an individual that requires medical treatment or results in death or loss of consciousness or inability to perform all job duties on any workday after the injury or temporary assignment to other duties or transfer to another job."

The scope of this study is restricted to accidents in which injuries have occurred while the individual concerned was actually engaged in maintenance or repair of one of the specified machines, that is, a haul truck, dragline, power shovel, or hydraulic excavator.

In addition to the number of accidents (frequency), two other measures of accident occurrence are used in this study: severity and incidence rate. In discussing the severity of injuries resulting in time lost from work, severity will be defined (*2*) as

[days off work + statutory days + (0.5 day restricted)].

Statutory days are assessed according to the schedule of accident severity; e.g., a fatality results in a charge of 6,000 statutory days against the employer.

Accident incidence rates provide a means for comparing the relative frequency with which an accident or accidents occur in two or more populations that have different levels of exposure to a given hazard or hazards. Accident incidence rates allow comparisons between the populations based on

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[3]Italic numbers in parentheses refer to the list of references preceding the appendix at the end of this paper.

equivalent data. It is usually expressed as the number of accidents divided by the number of hours worked: Because accidents are relatively rare events, this ratio may be quite small. By convention, mining accidents are usually expressed as the number of accidents per 100 workers per year:

(number of accidents × 200,000)/(total hours worked in 1 yr).

ACCIDENT INCIDENCE RATES

As noted, accident incidence rates are expressed as the ratio of number of accidents occurring within a population to total work time accumulated by that population. The MSHA mine accident data file can be utilized to obtain the number of maintenance accidents that occurred; however, because it does not provide a breakdown of worktime data, it is impossible to determine maintenance accident incidence rates. It is possible, though, to estimate the maintenance incidence rate. The basis of the estimate is the assumption that maintenance worktime was a constant percentage of total worktime during the 1978–85 period. If this assumption is correct, then the ratio of maintenance accidents to total worktime over that period should be indicative of and proportional to the maintenance accident incidence rate:

if $R = (A) \times (200{,}000)/M$,
and $M = (W) \times (K)$,
$R = (A) \times (200{,}000)/(W) \times (K)$,
then $(R) \times (K) = (A) \times (200{,}000)/W$,
where R = maintenance accident incidence rate,
A = number of maintenance accidents,
M = maintenance worktime,
W = total worktime,
and K = the percentage of total worktime devoted to maintenance.

By this analysis, the maintenance accident incidence rate is shown to be proportional to the ratio of maintenance accidents to total worktime. As seen in table 1, the overall accident incidence rate from surface metal and nonmetal mining showed a steady decline during the 1978–85 period. During that same time, the ratio of maintenance accidents to total worktime remained relatively constant, suggesting that the maintenance accident incidence rate did not decline along with the overall accident rate. If, in fact, the ratio of maintenance worktime to total worktime declined during that period (as has been suggested because of the prevailing economic conditions), it is more probable that the maintenance accident incidence rate actually increased.

Table 1.—Accident incidence rate in surface metal-nonmetal mining

Year	Worktime, 10^3 h	Injury accidents	Incidence rate	Maintenance injuries: Number	Maintenance injuries: Total worktime, 10^6 h
1978	70,784	2,477	6.91	99	1.40
1979	74,912	2,571	6.86	156	2.08
1980	72,404	2,069	5.72	149	2.06
1981	72,516	1,794	4.95	112	1.54
1982	44,612	968	4.34	33	.74
1983	38,144	760	3.98	61	1.60
1984	39,108	791	4.05	55	1.41
1985	35,058	760	4.34	57	1.63

ACCIDENT SEVERITY

The ADA program was used to sort the maintenance injuries from the MSHA surface mining accident records for 1978 through the third quarter of 1986. Only records for which the specified activity at the time of the accident was maintenance, and which involved the specified machines, were selected.

Using this criteria, records of 785 injury accidents were obtained. Of the accidents, 8 resulted in fatalities, 436 resulted in lost-time accidents, and 65 resulted in restricted time accidents. The total lost time was 11,024 days; of these, 5,966 days lost were due to accidents involving trucks and the remaining 5,058 days to the other three machine classes. A total of 71,405 statutory days was charged; 40,245 due to trucks and 31,160 due to the other machines. Finally, 666 days of restricted or limited duty work resulted from the injuries, in addition to the lost and statutory days. Of these restricted days, 283 were due to truck accidents and 383 were due to the other machines.

As might be expected, the personnel involved were predominantly mechanics and surface miners. Presumably, the surface miners were the operators of the equipment although it is not possible to establish this in each case. Table 2 presents data regarding injuries and occupations of individuals involved in maintenance accidents of all machines. The data in table 2 suggest that surface miners

Table 2.—Severity of maintenance injuries by occupation, all machines

Job title	Accidents	Severity, days lost[1]	Av severity, days lost
Surface miner	237	40,327	170
Mechanic-electrician	421	32,709	78
Other	127	9,771	77
Total or av	785	82,807	105

[1]Includes statutory days charged.

engaged in maintenance activity have more severe accidents than do the other groups.

Table 3 shows the type of accident involved in each injury for the combined data of all machines. Both frequency and severity of accident types are shown. Similar data are presented in tables 4 and 5 for the separate categories of trucks and other machines. The appendix provides a more detailed description of the various accident types.

Table 3.—Frequency and severity of accident types for all injuries

Accident type	Frequency	Severity, days lost	Av severity, days lost
Caught	154	48,525	315
Hit-by	264	16,396	62
Electric shock	7	9,624	1,375
Falls	150	3,892	26
Overexertion	98	2,236	23
Other	112	2,134	19
Total or av	785	82,807	105

Table 4.—Truck injury accident types

Accident type	Frequency	Severity, days lost	Av severity, days lost
Caught	72	26,375	366
Hit-by	122	16,744	137
Falls	77	1,854	24
Overexertion	51	649	13
Other	69	732	11
Total or av	391	46,354	119

Table 5.—Other machine accident types

Accident type	Frequency	Severity, days lost	Av severity, days lost
Caught	82	21,596	268
Electric shock	5	9,576	1,915
Falls	73	1,966	27
Overexertion	47	1,420	30
Hit-by	142	1,238	9
Other	45	297	7
Total or av	394	36,453	93

TRUCK SYSTEM AND COMPONENT ACCIDENT ANALYSIS

The previously discussed analysis has demonstrated the seriousness of maintenance accident problems in surface metal and nonmetal mining. However, before corrective action is possible, a greater understanding of the problem is necessary. Of particular concern is the determination of accident incidence rates corresponding to maintenance of specific vehicle subsystems and components. Maintenance tasks that have unusually high accident incidence rates can then be targeted for special attention (improved job design, tools, training, etc.).

As noted, the MSHA worktime data base is not suitable for determining these incidence rates because only industry-wide worktime totals are provided. It is impossible to determine the amount of worktime devoted to maintenance as a whole, much less the time spent on a specific vehicle system or component.

As a first step toward estimating the incidence rates for truck subsystems, a detailed breakdown of maintenance worktime was obtained from a large surface taconite (iron ore) mine. The data cover a 1-yr period, and include the total maintenance worktime devoted to each of 18 major subsystems and components for a fleet of end-dump haulage trucks. An analysis of this maintenance worktime data, together with MSHA maintenance accident data, yielded the maintenance accident incidence rates shown in table 6.

The haulage trucks subsystems were evaluated for accident frequency and injury severity. The objective of this analysis was to pinpoint subsystems that have a significantly higher degree of associated risk than expected, relative to the time spent working on the subsystem.

In order to evaluate the relative hazardousness of the subsystem, a standard statistical assumption was made. It was assumed, as a null hypothesis, that accident incidence rates would be equal between the various truck subsystems; that is, working 10 h on subsystem A would be equally hazardous to working 10 h on subsystem B. While practical experience suggests that this is not the case, such a null hypothesis is the first step in mathematically establishing the relative hazardousness of the different subsystems. Standard statistical evaluation proceeds by proving or disproving the null hypothesis of the systems. The data base was analyzed in terms of the proportion of accidents resulting from work on each subsystem and for the proportion of the number of days lost because of injuries resulting from work on each subsystem.

The frequency of accidents and seriousness of injuries were expressed as ratios of the observed values to the expected values. For example, if the time spent on the 24-V electric subsystem represented 5 pct of the total maintenance time spent on all subsystems, then the expected number of accidents associated with the 24-V subsystem, in keeping with the null hypothesis assumption that all subsystems are equally hazardous, would be 5 pct of the total accidents for all subsystems, resulting in an observed-expected frequency ratio of 5/5 or 1.0. If the number of accidents associated with that subsystem represented 10 pct

Table 6.—Truck subsystems, accident frequency and injury severity ratios, and excessively high accident rates or injury severity[1]

Subsystem	Frequency (observed/expected)	Severity (observed/expected)
Air system	0.7698	0.2805
Blower	1.1400	.0702
Box	.4438	.6267
Brakes	1.5663	1.6888
Cooling system	[2]4.8380	[2]4.8102
Engine	1.3115	1.7010
Exhaust	1.0813	.3415
Frame	.8763	.7268
Fuel system	2.3140	1.4535
Hydraulic	1.1350	.5714
Cab	1.0265	.7478
Steering	1.4872	2.4402
Suspension	[2]8.4386	[2]10.4737
Tires	[2]8.2092	[2]6.7449
Electric brake	.2292	.0069
Electrical power system	1.0074	.9448
Radio	.4857	Undefined
Wheel motors	.2228	.0184

[1]Total number of truck maintenance hours was approximately 13,000.
[2]Significantly more hazardous than other subsystems.

of the total accident frequency, then the accident frequency ratio for that subsystem would be 10/5, or 2.0, exactly twice as many accidents as expected. Similarly, a ratio value less than 1 would indicate fewer accidents than expected. Based on a comparison of values derived from these ratios with standard statistical tables (*4*), the original null hypothesis is proven valid or invalid.

Ratios of this type were calculated for the frequency and severity of injuries incurred in working on each of 18 haulage truck subsystems. As expected, the assumption of equal hazardousness implicit in the null hypothesis was disproven, and further analysis of the hazardousness of the truck subsystems was performed.

In order to assess the relative hazard of working on the subsystems, a 95-pct-confidence interval was constructed for the means of both the severity and frequency ratios. This confidence interval is a statistical statement of confidence that the average value of a group of values will fall within a specified range 95 times out of 100, with repeated sampling. This range of values takes into account the random fluctuation of the average value. As an example, consider rolling a die repeatedly. If it is a fair die, that is, if all faces of the die have an equal probability of coming up, the average value of the faces that show is 3.5. A 95-pct-confidence interval for this average value of a group of rolls might be that the average should be no less than 2.5 or no greater than 4.5. An average greater than 4.5 would suggest, with 95 pct probability of being correct, that the high numbers, 4, 5, and 6, were coming up more frequently than could be explained by change alone.

The confidence interval for both severity and frequency ratios indicated that a mean value of 1.0 would be statistically defensible for each. Once this was established, it was then possible to identify ratios that were outside the confidence interval. Ratios for any subsystem identified as being outside the confidence interval (either greater or less than the specified range) represent activities that are either more or less hazardous than all truck-maintenance jobs considered as a group. Ratios that are significantly less than 1.0 represent activities that are much less hazardous than the average; ratios that are significantly greater than 1.0 indicate more hazardous tasks.

In the case of the severity ratios, any subsystem with a value less than 0.58 may be considered as significantly less hazardous than the rest, and values greater than 3.6279 are significantly more hazardous. Frequency ratios less than 0.7478 may be considered as significantly less hazardous, ratios greater than 3.3170 are considered significantly more hazardous.

Table 6 presents the truck subsystems, accident frequency and injury severity ratios, and the truck subsystems for which accident incidence or injury ratios exceed the 95-pct-confidence interval.

As may be seen in table 6, three subsystems are identified as outside the confidence intervals for both frequency and severity of maintenance accidents, indicating that at the 95-pct-confidence level, the high observed frequency and/or severity cannot be attributed merely to random scatter in the data. These subsystems are cooling, suspension, and tires. Further analysis of these subsystems was conducted utilizing the data base compiled from accident narratives at the Bureau's Twin Cities Research Center (TCRC). Information extracted from the MSHA accident narratives that is not readily available in the ADA data base, such as specific part worked on, activity of the injured, etc., has been included in the TCRC data base. Brief characterizations of these accidents follow.

COOLING SYSTEM

Accidents involving the cooling system vary in their nature, according to the location in which they happen. Those that occur inside a shop tend to result from filling the system or when removing or installing components, particularly the radiator itself. Accidents that occur while filling the system result from poor or inadequate workstands. A small category of shop accidents involves workers becoming caught in moving components such as fans and belts.

It is difficult to ascertain what events are associated with removing or installing cooling subsystem components. It appears that the components are often inadequately supported while being removed or installed, and that access constraints require workers to be in unsafe positions when considering the inadequate supports of the component.

Field accidents related to the cooling system predominantly involve inspection of the system. It seems that workers are removing the radiator caps while the coolant is hot and under pressure. A small category of field accidents also involves removing or installing subsystem components, again predominantly the radiator. The accidents also seem to result from the use of inadequate workstands.

SUSPENSION

Shop accidents involving the suspension system tend to occur during removal or installation of subsystem components. The difficulty of gaining access to and supporting these components contributes to this type of accidents. A second shop activity that results in accidents is servicing the suspension system. These accidents seem to result from poor workstands and access problems.

Field accidents involving the suspension system seem to result from the difficulty of access to inspect the components. Poor or inadequate workstands were again identified as a contributing factor.

TIRES

Shop accidents involving tires predominantly involve removing or installing the tires. Moving the tires is also a major source of accidents. Explosion of the tires during servicing is a well-known hazard.

POTENTIAL METHODS OF DECREASING ACCIDENTS AND INJURIES

The occurrence of accidents has been described in the literature within two different conceptual frameworks. In the first model, accidents are described as the direct result of unsafe acts or unsafe mechanical or physical conditions. Some safety experts believe that as many as 90 pct of all accidents are the result of unsafe acts by the workers (*5*). Others believe indirect, or proximal factors to be the cause of accidents. These indirect causes include (1) a poorly designed workplace, tools, machinery, or other physical conditions of the environment, (2) an incompatible match between the worker and the job, and (3) failure to provide a supportive climate for a well-designed and well-executed safety program (*5*).

Complete acceptance of the first point of view blames accidents on the victim. The latter viewpoint lays the blame on the equipment. According to one authority (*5*), "The middle-ground realities are, first, that tools, machinery, and systems are for the most part not designed to be human fail-safe; certain kinds of errors made by humans will lead to accidents and injury. The second reality is that unsafe acts resulting from human errors, carelessness, or negligence do occur frequently in spite of the fact that the average employee is an intelligent, careful, and conscientious person. These unsafe acts and errors occur because of such things as lack of knowledge, lack of skill, lack of recent experience, inattentiveness, fatigue, and mental-physical environmental stressors."

Some of the factors suggested in this latter analysis as causes of accidents could be applied to maintenance safety. Previous research conducted by the Bureau under contract J0215007 has suggested that unfamiliarity with the job is related to the occurence of accidents. Maintenance of a piece of modern mining machinery is a complex task. A common complaint is that maintenance manuals are difficult to use, resulting in a sometimes ineffective manner of training maintenance workers (*1*). It is not surprising that knowledge of a safe way to work is as difficult to acquire as is the basic knowledge needed to perform the work. A potential way of addressing both problems is to revise the maintenance manuals, perhaps along the lines of the procedure charts used by some mine maintenance operations. These procedure charts present information used to perform some function, such as changing oil, in a simple, step-by-step list. Special hazards, required tools, and recommended safety procedures could be included for reference by the workers.

A second factor noted by Miller (*5*) is the compatible match of the worker with the job. Procedure sheets, similar to procedure charts, could be used to identify risk-associated actions, such as heavy lifting. For example, a maintenance mechanic may be required to lift a fairly heavy object during the course of a repair. Acceptable lifting loads vary among workers and also by the frequency with which they can be done in the course of a workday (*5*). Identification of such high-risk lifting required by a maintenance job might lead to specifications of who could lift, or it might require the use of some mechanical system to perform the lift. The use of such procedure sheets could enable the rating of the physical demand of a job, and high-risk workers could be selected out before injuries occur.

SUMMARY AND RECOMMENDATIONS

While the incidence of all types of accidents in surface metal-nonmetal mining appears to be decreasing, maintenance injury accident rates have remained constant and represent a high-cost item, with an average of 189 days lost per accident.

Caught, hit-by, falls, overexertion, and electrical shock account for most maintenance accidents in both accident frequency and injury severity. Maintenance of the cooling system, suspension, and tires of haulage trucks are particularly hazardous in terms of accident frequency and injury severity. Further analysis of maintenance of these systems suggests that better work platforms, improved methods of supporting heavy components, and improved methods of moving heavy components would be of benefit in reducing maintenance accident frequency and severity. A brief description of these acccident types is presented in the appendix.

Training and education of workers to appreciate the hazards associated with maintenance work would also appear to be of use. Periodic refresher training for maintenance workers; the implementation of simple process charts detailing procedures, tools, and potential hazards; the use of supports such as slings to support heavy items while they are removed or returned to the machine; and the use of stands to work on elevated machinery should be encouraged.

Most of these recommendations are based on common sense. The question may be posed: Why do people persist in working unsafely? A possible answer may lie in the psychological effects of the relative frequency with which unsafe behavior results in accidents. Not every incidence of unsafe work behavior is followed by an accident or injury. Consequently, the feedback a worker received about his or her work methods is mixed or misleading; e.g., "I've done it this way a hundred times before, and nothing bad has every happened."

A final recommendation would be to develop and apply behavioral controls to supplement the engineering controls already in use in the surface metal and nonmetal mining industry. Such controls could reduce the confusion in feedback to workers about the safety of their work behavior.

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APPENDIX.—DESCRIPTION OF SEVERE ACCIDENT TYPES

ELECTRICAL SHOCK ACCIDENTS

Electrical shock accidents are the most serious accidents in terms of associated severity. In a recent MSHA study (*6*),[1] electrical accidents occurring during maintenance were found usually to involve inadvertently brushing the hand or arm against a live circuit. Other accidents occurred when the individual did not realize that the component being worked on was in a circuit, or when power was inadvertently applied to a circuit that was being worked on.

Of 12 fatalities cited in the MSHA study, 9 involved persons who were not qualified to work with electricity. Many of these people were engaged in painting, cleaning, or other housekeeping duties around high-voltage circuits.

Recommendations made in this MSHA study include shutting circuits off and locking them out when work is to be done on or near them, including the replacement of fuses, and the installation of panels that provide a barrier between the worker and the circuits.

CAUGHT ACCIDENTS

Next to electrical shock, caught accidents are the most serious of all accidents in terms of their severity. When the relative frequency is considered, caught accidents may be considered as the most severe of all. Previous research has suggested the benefits of securing truck boxes when they are raised during maintenance and the use of nylon webbing slings where possible to suspend parts.

Many amputations have been reported from mechanics inserting fingers or hands into boltholes, etc., to check alignment (*7*). Many caught accidents and injuries result from the worker being in the wrong place, that is, being pinned between the object being moved and some other component of the machine. This can occur when a heavy part is removed without some support (*8*).

Another serious category of caught-type accidents involves the lubrication, adjustment, or removal of parts while the equipment is operating (*8*).

HIT-BY ACCIDENTS

The hit-by category represents a very large portion of truck maintenance accidents. Some of these accidents may be difficult to anticipate, others are not. For example, the use of platforms may prevent tools dropped by workers above the ground level from striking others who may be stationed beneath the worker to warn other individuals to keep out of harm's way.

OVEREXERTION

A sizable portion of all maintenance accidents and injuries examined in this study resulted from overexertion where overexertion refers to lifting or push-pull strains. There are current recommendations for such operations that can be used for the development of guidelines describing when it is safe to lift, when it is safe to push or pull, and when it represents an unsafe action (*9*).

Analysis of accident records suggest that a very common cause of overexertion injury is the removal or installation of a heavy part without supporting it in some manner (*8*).

FALLS

Of all the accidents investigated, nearly 21 pct occurred while the worker was getting on or off the equipment. A common accident of this type results from the workers carrying objects in their hands while climbing ladders or stairs. If they slip while doing so, they are less able to recover by grabbing the handrail.

Another common hazard related to falls is poor housekeeping in the work area. Debris may be difficult to eliminate from the work area in the pit, but power cords, tools, and other odds and ends represent a hazard on the shop floor, as do spills of lubricants and other fluids.

Accident analysis has shown that machine operators often slip and fall from their machines in the course of performing simple maintenance tasks such as fueling, checking lubricants, and checking coolant fluids (*9*), a finding confirmed by the present study.

Maintenance workers are often required to work at some height above the ground. Stable work platforms that adjust to the needed height should be available. The design of these platforms should take into account that the person working on them needs to be protected from slipping or falling off of them by siderails, etc. Additionally, the platforms should protect against parts and tools falling off. Suggestions for the design of work platforms are available in reference 11. Safety lines and harnesses should be employed as necessary when it is infeasible to provide platforms.

[1]Italic numbers in parentheses refer to items in the list of references preceding this appendix.

DETERMINING EFFECTS OF MANAGEMENT PRACTICES ON COAL MINERS' SAFETY

By Gregory Gaertner,[1] Paul Newman,[2] Shelly Perry,[3]
Gerald P. Fisher,[4] and Kenneth Whitehead[5]

ABSTRACT

A 3-yr study of 10 mining companies and 62 underground coal mines was undertaken by the Bureau of Mines to determine the effects of management practices on coal miner safety. Results presented in this paper should be considered tentative in that at this time the study is midway through the data collection period.

Findings to this point underline the importance of top management commitment to ensuring a safe, productive mining operation. In the sampled companies, a variety of practices were used by management to communicate safety priorities, although most companies focus on one or two mechanisms. Several effective management practices include safety-productivity incentives, disciplinary policies for unsafe behaviors, and concerted efforts to investigate accidents and distribute the results of these investigations. Less effective mechanisms include repeater programs and rehabilitation clinics. The most effective management practices allow participative implementation, followup, and evaluation. They are also generally forcefully advocated by some well-positioned company official, not necessarily in the safety function.

INTRODUCTION

As a result of the findings from a study performed by a task force of the National Academy of Sciences (NAS) (*1*),[6] the emphasis on the role of management in promoting underground safety has increased. The Bureau of Mines funded a 3-yr research effort to focus on specific managerial practices that tended to influence safety in underground coal mining. Westat, joined by the Bituminous Coal Research National Laboratories (BCRNL), and the Human Resources Research Organization (HumRRO), was selected to assess safety trends and practices across the mining industry that might help improve future safety policies, programs, and practices.

This paper traces the literature that relates mining safety and coal mine management. It also describes the methods employed in locating and collecting data from a cross section of 10 companies representing 62 mines, using a variety of data sources and data collection methodologies. Finally, it presents evidence on what specific policies, practices, and patterns appear to have measurable impact on encouraging safe underground mining.

The findings reported here should be taken as tentative for several reasons. First, this paper was prepared at the midpoint of the study's data collection period. As a result, analyses of trends over time, which will be available at the study's conclusion, (September 1987), are not currently possible. Second, some refinement in the existing measures will be attempted in the remaining year of the study. In sum, these results should be taken as preliminary and provisional, but nonetheless should be considered suggestive of directions for researchers and practitioners.

The paper begins with a review of relevant literature relating mine management and mine safety, in order to develop testable hypotheses for the analysis. It then describes the methods and measures, and reports some overall characteristics of the sample of companies. It reports the results of preliminary analyses, and presents discussion and summary outlining future directions for this and other research application.

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[6]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

LITERATURE REVIEW

The NAS study (*1*) formed the basis for the current investigation. Two of its conclusions influenced the direction of the present study toward organizational characteristics and practices as a determinant of safety. NAS found that management's commitment to safety, management-labor cooperation in the development and implementation of safety programs, and the quality of safety training provided were related to safety record. In addition, NAS also identified the relationship between higher production and lower injury rates. While the NAS study provided initial direction toward management practices as an influence on safety, it also became apparent that further specification was needed of the ways in which these factors influence observed differences in incidence rate.

ASPECTS OF ORGANIZATIONAL CLIMATE AND SAFETY

A number of management structures, interventions, and practices have been shown in previous research to be associated with low injury rates. These range from traditional practices such as training, to more recent and innovative programs, such as incentive systems and organizational development techniques.

Management Structures and Interventions

Among the processes found to have a relationship with decreased injury rates were decentralized decision-making, and flexible and innovative management in trying new procedures and programs (*2*). Davis (*3*), in a study of safety practices among award-winning companies, cites the importance of top management support and lower level participation to the success of safety programs. The necessity of participation of personnel (especially union personnel) in safety policy formation was confirmed by DeMichiel (*4*) and Pfeifer (*5*). The latter study suggested that in low-accident mines, management put greater emphasis on safety behavior, more often corrected hazardous conditions, and emphasized the maintenance of the company's safety record, putting less importance on production competition among sections or shifts.

While training is the main type of organizational intervention found in the mine industry, Goodman (*6*) noted that the introduction of other organizational development methods has increased in underground coal mining. Two major comprehensive organizational development experiments have been performed in U.S. mines. Goodman (*7*) described a major intervention at the Rushton coal mine in Pennsylvania. The focus at the Rushton mine was on improvement of both productivity and quality of working life. Labor-management problem-solving groups were developed to diagnose problems, and introduce, monitor, and modify change. Through reorganization of a work section into an autonomous work group, the program produced changes in work methods (authority system, decisionmaking, and communication) and the pay system. Fiedler (*8*) introduced training in leadership and supervisory skills and techniques such as team building, problem solving, coaching, and supervisory skills. Results of the Rushton study indicate that there was an increase in miners' knowledge of new mining practices and safety procedures, as well as beneficial changes in communication, interaction, and level of responsibility taken by individuals. The Fiedler (*8*) study cites results including safety improvement, while productivity was not adversely affected.

Comparatively little research documents the effects of training on safety. What research does exist reviews the current state of training and calls for improvement in the instructional aspects of training, rather than assessing training's long-term utility (*9-10*). In general, a strong relationship between generalized safety training and lower injury rate has not been shown, although some utility has been found for training targeted toward specific problems, such as the reduction of causes of certain injuries (*11*). Again, the commitment of management to safety programs was found to be the best predictor of training effectiveness.

Incentive Systems

Incentive systems, a development in the industry following the 1978 wage agreement, have been implemented on a wide basis (86 pct of mines, according to Sloan (*12*)). Compensation systems are usually composed of a base rate and additional bonus for production above a specified target. Most plans include safety factors in addition to or as limiting conditions on production bonuses, although there are financial disincentives for nonproduction activities that may affect safety (*13*). Many new incentive plans exist, but little systematic evaluation has been done of their effects on productivity or on safety.

The literature review identified only two case studies describing the relationship between a production incentive system and safety. Stanek (*14*) described the effect one company's bonus program has had on safety, a decrease in incidence and violation rates. However, a very recent study by Page (*15*), also seems to point to the use of incentives in high-production, safe mines.

Case Studies of Safety Environments

In order to provide a portrait of current underground mining safety practices, the results of case studies aimed at identifying factors related to safety are presented, based on Braithwaite's study (*16*) of the safety environments of five companies with the lowest accident rates in the early 1980's. The following characteristics found to be responsible for safe performance were:

1. *Safety practices integrated vertically throughout the company.*—These include individual-level practices such as safety-related job analysis, training by supervisors of miners in safe job procedures; weekly contact by supervisors with miners, for informal training and monitoring of safety practices; formal monthly safety observations of each employee; and administrative maintenance of employee safety records.
2. *Accident investigation.*—Investigation was thorough and multilevel, and attempted to identify the underlying cause of the accident. Investigations pinpointed types of violations that caused a number of injuries, or physical conditions contributing to accidents and injuries.
3. *Communication.*—Sharing of information was promoted at meetings where accidents were analyzed and safety innovations discussed. Peer pressure was also applied to managers with poor safety records, through discussion of their problems and plans for remediation.

4. *Top management commitment.*—Often, safety had a higher priority than production or was considered an integral part of production.

Across the board, safety personnel were found to have a strong informal leadership position, backed by top management commitment to safety. Responsibility was placed on the line manager to ensure safety within his or her area of accountability. The successful companies combined a centralized focus on safety through policy setting with decentralized safety practices through line management responsibility for implementation and performance.

HYPOTHESES

Based on the results of previous research, the following hypotheses were formulated to guide the investigation into companies and mines:

1. *Top management commitment to safety is associated with miner safety.*—Corporate leadership has been shown in a number of areas of research to be a critical factor of influence on safety. In the several studies, however, top management commitment has been defined in different ways. This study will specify critical components of commitment, its development process, and application to safety practices.

2. *Safety strategies effective in the reduction of overall injury-accident rates will integrate various management control mechanisms to ensure consistency and use.*—It was contended that a strongly advocated safety policy, combined with decentralized governance and reinforcement of safety practices, is most effective in ensuring low accident and injury rates. Simultaneously, the emergence and implementation of strategies at lower organizational levels are likely to interact to produce favorable outcomes.

3. *The existence of a safety incentive system is associated with better safety records.*—The existence of a company incentive program that rewards employees for safe performance will result in a lower injury rate compared with rates of companies with no programs. The mechanisms responsible are likely to be the demonstration of top management commitment to safety and motivation of employees to exert informal control over on-the-job safety practices.

4. *Organizational climate factors and labor-management relations are influential on safety records.*—Participative decisionmaking and decentralization of authority are hypothesized to be influential on safety. Previous research has provided support for the benefits of participation and delegation, which are thought to foster consensual behavior and motivation for safety. Adversarial labor-management relations are hypothesized to be inversely associated with mine safety. This study will attempt to clarify whether unsafe conditions create an adversarial climate, an adversarial climate causes more injuries, or additional factors may be influencing both variables.

5. *Safe coal mining operations tend to be productive ones.*—This hypotheses has received consistent support in previous research. What has yet to be specific, however, is what management practices are responsible for this relationship.

METHODS

In-depth case studies were conducted with a sample of coal mine operating companies that had volunteered to participate in the research. Site visit teams examined numerous elements of company safety and management programs, as well as a combination of statistics reported to the Mine Safety and Health Administration (MSHA), statistics maintained by the companies themselves, and measures of management climate and policy enforcement as reported by managers, supervisors, and hourly employees.

COMPANY PARTICIPATION

Project staff contacted safety directors and other known industry contacts at the coal producing companies to solicit voluntary participation in the research effort. The final sample was composed of 10 coal mine companies, operating 62 mines. Variety was achieved in the final sample in terms of geographical dispersion, company size, ownership patterns, number of mine sites, union-nonunion representation, and safety records.

Mine companies and sites were located in eight different States; Virginia, West Virginia, Pennsylvania, Ohio, Illinois, Kentucky, Alabama, and Colorado.

Participating companies were diverse in size, whether measured by market share, number of operating mines, or employee population. Two of the ten companies rank among the Nation's largest coal producers, while several of the companies have only one operating mine. The majority of participating companies have more than one mine and operate in a single State.

Miners in 7 of the 10 mining companies were represented by the UMWA; the other three companies were nonunion.

Overall, the study represents a cross section of companies with excellent safety records as well as others across a full range, including some with lost-day accident rates exceeding the national average.

Table 1 provides an overview of the 10 companies that agreed to participate in the field study. The table provides the overall incidence rate for each company, as calculated from accident-injury, production, and employment statistics provided by the Mine Safety and Health Administration (MSHA). The rates are calculated across the 5-yr period from 1980 through 1984, and across all mines identified as operated by the participating company. While the national average for incidence rates based on all injuries in underground coal mines was 10.07 in 1983, the 10 companies average incident rate for 1980 through 1984

Table 1.—Summary descriptions of participating companies
(Annual averages of 1980-84 5-yr period)

Company	MSHA incidence rate	Production, st	Employees	Employee hours	Hours per employee
1	15.25	838,246	277	548,508	1,980
2	9.94	328,322	113	199,508	1,763
3	2.79	404,042	117	236,606	2,022
4	8.83	925,345	474	888,226	1,879
5	10.32	561,646	172	307,385	1,787
6	12.96	119,797	59	94,505	1,602
7	7.76	55,081	28	28,629	1,022
8	11.97	279,579	124	220,496	1,778
9	4.22	512,468	170	358,671	2,110
10	6.38	143,568	18	36,055	2,003
Av	9.04	416,810	155	291,828	1,883

was 9.04. The 10 companies can, therefore, be considered a fair cross section of coal producing companies in terms of historical incidence rates.

Site Visits

Site visit procedure involved the collection of quantitative and qualitative data for case study descriptions and later analyses. Information was obtained from a number of sources while on site, including—

Interviews with mine and company management representing all levels of the organization;

Mine records (where available) on employment, production, turnover, absenteeism, time off, and disability compensation;

Safety department records on accident and injury histories, as well as inspection burden and violation history;

Focus group discussions with supervisors and hourly personnel; and

Responses to semistructured interview questions regarding safety policies and their reinforcement.

A significant aspect of the present study, which sets it apart from other investigations of coal mine safety, is the application of organizational models not typically associated with the management of coal mining organizations. For example, in the first two sections of the site visit outline, the coal company is discussed as an organization (e.g., functional departments, organizational structure, and lines of responsibility) and in terms of recent corporate history (e.g., primary business of controlling interests, terms of partnership arrangements, and stockholders' equity).

The semistructured interview format is designed to explore both formal and informal company policies and training functions, their formation, communication, and reinforcement, as well as subjective impressions of and reactions to these policies.

Group interviews, known as focus groups, were conducted separately with production supervisors and with hourly personnel. Focus group sessions permit respondents to interact freely (and to disagree with one another) on specified topics, but maintain the flexibility to discuss issues of concern to the respondents.

Data were obtained from MSHA on all accidents reported by the selected mines during the 1980-84 period. MSHA also provided annual summary statistics for the same 5-yr period, for the selected mines' total mine employment, total employee hours, total production (in short tons), and violations citations. These three data sources were matched and merged at the company level. That is, accidents and violations data were sorted by company and year. Next, counts of each degree of injury, number of violations, and number of significant violations (serious and substantial (S&S)) were computed for each company and year. These company profiles were then matched with the company-level production and employment data so that incidence, violation, and productivity rates could be calculated. (Rates serve to normalize the different mines for their employment and production size.) These data are presented in table 2.[7] Also reported in table 2 are average annual violations and average annual S&S violations per mine.

Table 2.—Status of participating companies on outcome variables[1]
(Annual averages of 1980-84 5-yr period)

Company	MSHA incidence rate	Production, st/h	Violations	
			Total	S&S
1	15.25	1.44	35.16	16.70
2	9.94	1.65	30.60	26.50
3	2.79	1.71	3.45	1.25
4	8.83	1.04	38.80	13.40
5	10.32	.91	24.20	6.27
6	12.96	1.11	1.60	.80
7	7.76	1.92	4.60	1.20
8	11.97	1.27	7.80	4.20
9	4.22	1.01	21.97	9.10
10	6.38	3.58	.97	.20
Av	9.04	1.56	16.91	7.96

S&S Serious and substantial.
[1]Owing to tempory mine shutdowns and voluntary participation of mines within companies, companies cannot be identified by these data.

Incidence rate statistics computed from the research data base were compared with those reported by the companies themselves during the site visits. These two measures agreed to within 10 pct at all but one company.

Next, comparisons were made of statistics from the 62 sampled mines with the descriptive statistics reported by NAS (*1*). A brief review of these comparisons is provided in table 3. In the table, injuries in the seven categories of accident types reported by the NAS are cross-tabulated by degree of injury. A comparison of the marginal percentages for the data of this study with results reported by NAS reveals a similar distribution of accidents among the seven types. That is, the largest proportion of injuries falls into the category of materials handling in both data sets (38 pct compared to 34 pct in the NAS report). The next largest category, slipping and bumping, also mirrors the NAS distribution (26 pct versus 24 pct). In sum, the order of proportions among accident type categories is identical to those reported by NAS.

In terms of injury degree, the summary lines at the bottom of table 3 display a similar trend in incidence rates for each injury degree. This holds true in spite of the different timespans covered by the two data sets (1980-84 versus 1978-80) and significant differences in sample sizes. These findings are characteristic of the kinds of accidents and degree of injuries generally observed in coal mining, and are therefore expected to remain relatively constant across years.

[7]It should be noted that temporary mine shutdowns during the years 1980 to 1984 and voluntary participation of selected operating mines within companies alter these statistics somewhat from MSHA records. Individual companies, therefore, cannot be identified from these computed rates.

Table 3.—Distribution of reportable injuries by degree of severity and type of accident for 1980-84

Accident type	Severity, degree			Total	Distribution, pct	
	1	2	3-5		This study	NAS (1)
Roof-side falls ..	11	1	393	405	7	10
Haulage	2	7	698	707	12	14
Machinery	3	21	710	734	13	14
Electrical-explosive	1	0	160	161	3	3
Material handling	0	51	2,176	2,227	38	34
Slipping-bumping	4	5	1,530	1,539	26	24
Other	0	0	49	49	1	1
Total	21	85	5,716	5,822	100	100
Injury rates:						
This study	0.04	0.16	10.69	9.04	NAp	NAp
NAS (1)	0.07	0.17	11.80	12.00	NAp	NAp

NAp Not applicable.

Qualitative Data Coding

Selected safety policy and company profile information was consensus coded based on the site visit reports. The following major topics were included in the content coding scheme (coded for presence or absence):

1. Whether there was a written safety policy.
2. Whether safety incentives (monetary or awards) were offered.
3. Whether combined safety-productivity incentives were offered.
4. Whether the company had formal investigations of lost-time accidents more extensive than those required by law.
5. Whether the company had (and used) disciplinary policies applied to safety violations against miners and supervisors.
6. Whether the company distributed information for safety meetings.
7. Whether the company had special programs for miners suffering repeated accidents.
8. Whether the company had special programs for injury rehabilitation.

Codes were assigned to each company based on details in the case study reports, notes from site visit interviews and focus groups, and materials provided by the participating companies. As shown in table 4, 9 of the 10 participating companies provide formal written safety policies. Seven of the companies had some type of safety incentive program in place, and three companies had incentives programs that rewarded both production and safety. (Production incentives were never found implemented in the absence of related safety incentives.)

Table 4.—Proportion of participating companies reporting various elements of safety programs

Policy element	*Mean*
Is there a written safety policy	0.90
Are there incentives for safe operation	.70
Are there incentives for combined safety and production	.30
Are there special accident investigations beyond requirements ...	.33
Are safety discipline policies used	.50
Does company distribute information for safety meetings	.78
Is there a program for accident repeaters	.50
Is there a rehabilitation program	.28

Less common were policies on followup investigation programs (beyond the required filing of supervisor's and safety director's reports). These were defined as any formal program, initiated in the aftermath of an accident or injury, which was designed to learn more about the circumstances of mine accidents and injuries. Three companies indicated that specific procedures were in place for such a review of each occurrence, including in two cases a formal counseling session with each employee involved.

Employees in six of the participating companies cited specific disciplinary actions (e.g., suspensions, penalties in job posting, priority in layoff-recall decisions, or dismissals) that would result from identified unsafe work practices, such as going out under unsupported top. Five operators had established policies to deal specifically with repeatedly injured employees, and two had established rehabilitation programs and/or clinics for common injuries, such as low-back strains.

ANALYSIS AND RESULTS

In the analysis to follow, results are presented relevant to the hypotheses developed. The discussion begins by reviewing the interrelations among outcome variables to be utilized in the analysis. Results on top management commitment, aspects of safety policy relating to safety and productivity, and the effects of perceived policy clarity and consistency are then reviewed. Data on labor-management relations and the role of safety committees are discussed. Finally, evidence on the staffing and organization of the safety function is reviewed and summary conclusions and discussion are presented.

OVERVIEW OF MINE SAFETY AND PRODUCTION OUTCOMES

Four major outcomes are utilized in the results to follow—MSHA incidence rate, tons per employee hour, number of MSHA citations per mine, and number of MSHA S&S citations per mine. The injury and productivity rates were computed by adding the total number of reported injuries (or the total number of tons mined) over the 1980-84 period for the company, and dividing that total by the total number of hours worked for the company

over the period (times 200,000). The violation and S&S counts were the averages of the mines owned by the company for the period.[8]

Table 5 presents the intercorrelations among these outcomes. Cell entries in table 5 are correlation coefficients, using company level rates for the 1980-84 period. As should be clear, incidence rates are negatively associated with productivity (r = −0.30), and positively associated with citations (0.31) and S&S citations (0.31).

Table 5.—Intercorrelations among safety and productivity outcomes

Correlation coefficient	1	2	3	4
MSHA incidence rate[1]	1.00	−0.30	0.31	0.31
Short tons per employee hour[1]	−.30	1.00	−.47	−.27
Citations per mine[1]	.31	−.47	1.00	.84
S&S citations per mine[1]	.31	−.27	.84	1.00

S&S Serious and substantial.
[1]Av over 1980-84 5-yr period.

Productive companies tend to be cited less than unproductive ones (r = −0.47 with citations and −0.27 with S&S citations), and the two types of citations are closely associated (0.84). Thus, in this sample, as with much previous literature, productive companies tend to be safe companies. This finding is particularly important in the discussion that follows.

TOP MANAGEMENT COMMITMENT TO SAFETY

A variety of previous studies have pointed to the role of top management commitment to safety. Perhaps not surprisingly, there was very little in the interviews with top mine managers that allowed direct discrimination between companies where top management was committed to safety and where it was not. In fact, it is doubted that top management was indifferent to safety in any of the sampled companies. Certainly, nowhere was there an attitude of fatalistic acceptance of high or even moderate injury rates.

There were, however, differences in the ways and extent to which top management expressed its commitment. The first, and most obvious, was in the company's safety policy. A second was in the company's choice of vehicles for stressing safety.

Successful companies relied heavily on one or two means of promoting safety. In one company, the means was training and the use of computerized technology. In a second, it was in applying engineering knowledge to production and safety problems. In a third, it was a regular formal program of management audits of safety performance combined with regularized formal contacts. There did not appear to be one best vehicle for promoting safety, but all had several features in common.

First, the means selected represented a complete sequence of activities in which the workforce could participate and which could be implemented, monitored for completion, and fed back to management and workforce. Followup was a critical part of the safety program. Second, the means were promoted by a well-situated advocate, not necessarily the company president or safety director, who was able to utilize the vehicle to emphasize safety. Third, there was frequently considerable pride in the vehicle as being invented at and being unique to the company.

This reliance on safety vehicles is in close accord with recent general studies in successful management (*17*). These studies stress the need for a common set of beliefs, a structure of action-oriented participative processes, and the critical roles of advocates in fostering a climate of organizational effectiveness. These points will be further refined in subsequent data collection.

EFFECTS OF SAFETY POLICY

As noted in the review of the literature, many studies have suggested that safety policy plays a key role in mine safety. Unfortunately the extant studies, with few exceptions, do not suggest which elements of safety policy were important in influencing safety; nor, frequently, do they distinguish between policy as stated and policy as perceived in the mining companies. The studies also were generally unable to place the elements of the policy in the overall company context. The field methods and data collected in the current study allow for much more careful scrutiny of the relations among elements of policy, reactions to policy, and effects on safety, productivity, and MSHA violation rates.

Table 6 relates policy elements present in the current sample of companies to rates of injury, productivity, and MSHA violations. The eight policy elements discussed previously were scored as either present or absent at each company.

As noted in the "Methods" section, these scores were derived from on-site interviews and document collection. The elements were scored as present or absent for each of the companies, and these variables form the rows of table 6. Two types of incentive strategies were coded because some companies offered safety incentives or awards alone, while other companies used a combination of production and safety to reward employees. The most common form was to award a bonus on tonnage beyond some norm only if no reportable injuries occurred. No companies offered production incentives without safety conditions.

Policy as perceived is measured by the responses of supervisors and hourly personnel following the focus groups described above. Focus group participants (table 6) were asked, on a five-point (strongly agree to strongly disagree) scale, to respond to the following statements:

1. This company's policies on safety are *clear to me*.
2. This company's policies on safety are *consistent*.
3. This company sometimes pushes productivity at the expense of safety.
4. This company favors automatic temporary roof support (ATRS) systems.

[8]Pearson's product-moment correlations vary between −1.00 (where positive values of one variable are associated with negative values of the other) through 0.00 (where the two variables are independent) to +1.00 (positive values of one variable are associated with positive values of the other).

Table 6.—Relationships among policy elements and safety, productivity, and rated policy outcomes

Policy elements	Companies	1980-84				Focus group results[1]			
		MSHA incidence rate	Production, st/h	Citations		Rated policy		No pressure for production over safety	Support for ATRS
				Per mine	S&S	Consistency	Clarity		
Is there a written safety policy:									
Yes	9	9.06	1.62	14.5	7.4	1.61	1.88	1.09	1.63
No	1	8.83	1.04	38.8	13.4	1.88	2.19	2.31	1.50
Are there incentives for safe operation:									
Yes	7	9.04	1.70	16.4	6.2	1.47	1.60	1.05	1.51
No	3	9.04	1.26	18.1	13.1	1.96	2.53	1.56	1.83
Are there incentives for combined safety and production:									
Yes	3	5.64	2.41	3.0	.6	1.03	1.05	.39	1.35
No	7	10.50	1.20	22.9	8.7	1.94	2.34	1.64	1.75
Are there special accident investigations beyond requirements:									
Yes	3	6.32	1.33	11.1	4.0	1.62	1.62	.99	1.78
No	6	10.19	1.79	18.6	10.8	1.55	1.95	1.22	1.52
Are safety discipline policies used:									
Yes	5	8.20	1.94	16.6	7.9	1.24	1.34	.87	1.39
No	5	9.88	1.19	17.2	10.0	1.95	2.37	1.50	1.80
Does company distribute information for safety meetings:									
Yes	7	8.05	1.65	9.2	3.4	1.55	1.86	1.14	1.66
No	2	9.38	1.35	34.7	9.3	1.94	2.10	1.51	1.47
Is there a program for accident repeaters:									
Yes	5	10.15	1.49	10.5	6.8	1.42	1.81	1.02	1.79
No	5	7.93	1.64	23.3	9.9	1.81	1.99	1.38	1.48
Is there a rehabilitation program:									
Yes	2	10.13	1.28	27.4	14.3	2.04	2.30	1.33	1.51
No	8	8.77	1.64	14.3	6.4	1.52	1.80	1.19	1.64
Overall mean	NAp	9.04	1.56	16.9	8.0	1.64	1.91	1.22	1.62

ATRS Automatic temporary roof supports. NAp No applicable.
[1]Low scores indicate greater consistency, clarity, lack of production pressure, and support for ATRS.

Items 1, 2, and 4 were scored as 1 for strongly agree and 5 for strongly disagree. Item 3 was reverse scored, so that a high score means that the company *is* seen as pushing productivity over safety. The items can be interpreted in the same way as injury rates—low scores represent desirable outcomes.

Companies with a written safety policy have about the same incidence rates as those that do not (incidence rates of 9.06 compared with 8.83 respectively). Of course, as should be noted, only one company did not have a written safety policy; thus, not much can be said as to the effect of the presence of a safety policy in itself.

Some policy *elements*, however, are clearly associated with safety. Companies with combined safety and production incentives, companies with formal investigation policies, and companies with safety discipline policies do tend to have lower incidence rates over the 5-yr period than companies that do not.

The association between safety-production incentives and safety is particularly striking, especially in light of the relative lack of effect of safety incentives alone. Companies with combined safety and production incentives averaged only 5.64 reported injuries per 200,000 h annually; companies without combined production-safety incentives averaged an 86 pct higher rate annually. Examination of interviews and case study materials clarify the difference between safety and production incentives. Safety incentives not tied to production tended to be relatively inexpensive and symbolic (T-shirts, caps, decals), and generally did not indicate a serious commitment by management to safety in the eyes of the supervisors and hourly employees. Rather they were usually intended as "reminders to the men, to keep thinking about safety," as one manager put it.

Combined production-safety incentives seem far more effective, and generally more costly. In one compnay, the cost of the production-safety incentives was 25 cents per ton; in another it was 81 cents per ton. Nonetheless, the incentives appeared to be effective. As one supervisor put it, the incentive program in place in his company "made management put their money where their mouth was." Certainly, there are strong effects of safety-production incentives on perceptions of policy clarity and consistency, indicated in the last four columns of table 6.

Companies with safety-production incentive programs are more likely to be seen as having clear and consistent safety policies. They are much less likely than other companies to be seen as pushing production at the expense of safety. These findings are in close accord with Page (*15*); however, several caveats should be noted.

First, the design of some incentive systems makes them less effective. For example, in one company where incentives are based on *no* lost-time accidents for a month, the first accident tends to be followed by several others as the incentive is no longer in effect. Second, the design of the incentive system cannot be divorced from an overall management strategy supportive of safety. Third, there is reason for concern that incentives seem so effective that

many observers are concerned that the incentives simply encourage miners not to report actual injuries. In one company that has strict safety-only award program, managers were reluctant to implement a combined safety-production incentive for fear of making miners work injured to avoid reporting injury and losing their incentive pay.

There is some empirical support for this concern to be drawn from this study. For example, if it is assumed that the main effect of incentives is to suppress the reporting of minor injuries rather than to increase safety consciousness, then the difference between companies with and without safety-production incentives should be less when more serious injuries are considered, because these cannot easily be ignored. This is in fact the case. The difference in reported injuries between companies with and without incentives was 4.86 per 200,000 employee hours in the average year. However, the difference in rates for days-lost injuries is smaller—the average rate of days-lost injuries over the period for companies with incentive programs was 7.17 per 200,000 employee hours; for companies without them it was 9.70, a difference of 2.53. Thus, there may be some tendency for safety-production incentive programs to both encourage safe work and discourage injury reporting.

The associations between safety disciplinary policies and formal investigations (and to some extent, the provision of materials for safety meetings) on the one hand, and safety on the other, are less easily explained, and nearly as strong.

About half of the companies visited had stong safety discipline policies. There was a strong association with whether the company was organized—unionized companies were less likely to have safety discipline policies. However, several unionized companies had special safety discipline policies developed in collaboration with the UMWA. When present, such policies seem to have an effect on safety (the difference in incidence rates between companies with and without special discipline policies was 1.66 per 200,000 hours annually).

The importance of the disciplinary policy seemed to be less punitive than indicative of top managerial commitment to safe operations. In one company, for example, it was the policy to send home both a miner and his or her supervisor if the miner went out under unsupported roof. One member of the research team, while underground and out of earshot of safety personnel, asked a miner whether the policy was serious. He replied, "I got sent home last week, and my face boss did, too." When asked what effect this had, the miner said, with obvious understatement, "We're both a lot more careful about going out under unpinned top now." Certainly where special disciplinary policies are present, focus group results suggest that safety policy is more likely to be seen as clear and consistent. The results for investigations and information distribution are similar.

The common thread of safety-production incentives, discipline programs, and special investigation procedures is that in each, special attention by management is directed to problems of safety. This attention was sometimes popular (incentives), sometimes not (discipline), but in each case showed special focused attention to safety. It may be that this top management attention is as important to safety as the specific policy element by which it is expressed.

Two policy elements stood out as *not* effectively reducing reported accidents—repeater programs and rehabilitation clinics. Companies that had special programs to deal with repeaters and special programs to supervise or speed rehabilitation from injuries had higher injury rates than companies without the special programs.

Two explanations come to mind. First, it may be that companies with severe injury problems were driven to undertaking repeater and rehabilitation programs. Managers at companies supporting such programs frequently cited the costs of compensation and extended convalescence as reasons for the programs. Alternatively, it may be that at companies where repeater and rehabilitation programs are supported, there is a tendency for safety to become part of an adversarial atmosphere between management and the workforce.

The focus group results suggest that workers in companies where rehabilitation programs are undertaken tend to feel that the company's safety policy is less consistent and less clear than in companies where such programs are absent. Interviews conducted with supervisors and hourly personnel during site visits suggest that miners frequently were distrustful of such programs. The interview results for repeater programs are less clear cut. There was often support in the workforce for counseling and weeding out miners who were repeatedly injured, and repeater programs were found in companies where labor-management relations were quite good.

Findings of major importance to this study and to coal mine safety overall are contained in the MSHA incidence rate column of table 6. By way of summary, *policies associated with company-level safety are also closely associated with company productivity.* Safety-production incentives and discipline policies, in particular, tend to be found in companies that are both safe and productive.

The association between safety and productivity is demonstrated even more clearly in the data in table 7. This table presents correlations among the focus group ratings of policy clarity, consistency, company pressure for production over safety, support for ATRS, and among injury rates, productivity rates, and counts of citations and S&S citations. Again, the results suggest that in companies where safety policies are seen as clear and consistent, where production pressure is not seen to come at the expense of safety, and where ATRS is seen as supported, reported injuries are lower and production is markedly

Table 7.—Correlations among rated policies and safety-productivity outcomes, 1980-84

Mean responses[1] to—	MSHA incidence rate	Production, st/h	Citations	
			Per mine	S&S
Company's safety policy is clear to me	[2]0.48	[2]−0.75	[2]0.70	[2]0.59
Company's safety policy is consistent	[2].63	[2]−.67	.32	.20
This company sometimes pushes production over safety	.42	[2]−.75	.51	.14
This company supports automated temporary roof supports	.40	[2]−.76	−.09	−.13

[1] 1st, 2d, and 4th scored from strongly agree to (1) to strongly disagree (5); 3d reverse scored for ease of interpretation.
[2] Statistically significant; $p < 0.10$.

higher. In fact, the associations between reactions to policy and productivity are even stronger than the associations between policy reactions and safety.

The main safety policy elements (table 6) that are associated with safety and productivity are also associated with low rates of violations and with low rates of significant and substantial violations. Safety-production incentives, information distribution, and safety investigations are all associated with low rates of citation, and low rates of S&S citation. As should be clear, the results are the same (table 7) for rated policy from the focus groups.

Other Elements of Policy

For several other elements of policy, only anecdotal information can be provided at this point.

Training, for example, seems to have to be pervasive but have little systematic impact. Only one company offered training in addition to that required by law. That company does have very low accident rates and high productivity, but because that company is remarkable in several respects, it is difficult to attribute its safety and production performance to training alone. It is, however, noteworthy that the company's managers *do* heavily emphasize the role of training in their overall safety strategy.

Based on the comments received in focus groups, the quality and relevance of training varies widely among the sampled companies. In response to cost pressures, many companies have cut back severely on in-house training staff, in preference to contractor-supplied training. Three companies have the bulk of their training supplied and delivered by local university staff. There are no apparent safety effects of these trends, but in general these cutbacks are recent. The safety and productivity performance of companies experiencing training cutbacks will be tracked in the final year of the study, for inclusion in the final report.

A second element about which only anecdotal evidence can be presented is the role of safety meetings and contacts. All companies had, as part of their policy, weekly safety meetings or huddles on the section, ranging in duration from 5 to 30 min. Thus, there is no clear-cut variability in this element. Further, only one company had a regularized program of safety contacts, so that there is little systematic variability in this element.

There was wide variety in the utility and relevance of the safety meetings, based on the reports of the focus groups. In subsequent analyses, the comments on safety meetings will be coded to provide more specific feedback to industry. Preliminary evidence suggests that the quality of safety meetings varies with the amount of specifically relevant material supplied by the company to the section supervisors and with the extent to which supervisors take the meetings seriously. This latter is probably related to the overall approach to safety in the company.

Multivariate Models of Safety Policy Elements

The preceding discussion distinguished between policy as stated in interviews with mine management and in documents and policy as perceived in focus group interviews with mine supervisors and hourly employees. One reasonable question is, which of these two is more important in producing safety and productivity results? On one hand, it is reasonable to argue that policy as stated is the ultimate arbiter of managerial action—if the policy exists, it is the touchstone for what is allowed, what is not, and what is ambiguous. Interviews with managers matter-of-factly convey this impression. When asked how the company deals with accident investigations or with incentives, managers typically referred to the company's policy. On the other hand, academics and practitioners are more likely to attend to policy as perceived as a reliable guide to understanding and prediction. This is especially true in safety management, where so much depends on the voluntary compliance of supervisors and hourly personnel, it might be argued that policy as stated is irrelevant unless it is understood and acted upon by those to whom it is intended to apply.

The data allow at least an illustrative test of these alternative arguments, in that data were collected on both policy as stated and policy as perceived so that comparison of their effects on safety and production outcomes is possible. The results of this illustrative test are presented in table 8.

Table 8.—Comparing effects of stated and rated policy on safety and productivity[1]

	Production-safety incentives		Overall	Difference
	Yes[2]	No[3]		
MSHA incidence rate:				
Without accounting for rated consistency[4]	5.64	9.79	8.35	4.06
After accounting for rated consistency	7.22	8.91	8.35	1.69
Short tons per employee hour:				
Without accounting for rated consistency[4]	2.41	1.17	1.58	1.24
After accounting for rated consistency	2.22	1.26	1.58	.96

[1]Results differ slightly from table 1 because focus group results were not available for 1 company.
[2]3 mines.
[3]6 mines.
[4]Difference in means significant; $p < 0.10$.

Table 8 presents results for MSHA incidence rates and results for productivity. The means of companies with and without safety-production incentive plans are presented, ignoring safety policy consistency ratings taken from the focus group.[9] Effects of rated consistency of safety policy were removed statistically,[10] and adjusted means and differences in them are presented. In nontechnical terms, table 8 presents the mean incidence and productivity rates companies with and without safety programs would be expected to have if these focus groups had safety policies rated as equally consistent.

The results suggest that perceived consistency in safety policy is probably more important than the mere presence of safety-production incentives in fostering low incidence rates. When rated consistency is ignored, the difference in incidence rates attributed to safety-production incentives is a statistically significant 4.06. When rated consistency is statistically controlled, the difference attributed to safety-production incentives drops to an insignificant 1.69. However, for productivity, effect of

[9]The results differ from those presented in table 6 because for one of the companies focus group results were not available.
[10]Technically, this is accomplished by entering rated consistency as a covariate and removing its effects on the dependent variable (incidence rate or productivity) before recomputing the difference in means.

policy as stated is probably stronger than consistency in safety policy. The difference drops from 1.24 to 0.96. This is perhaps understandable in that the variable controlled relates directly to safety policy consistency, rather than consistency of productivity policy. Nonetheless, even the latter result suggests that part of the productivity effect of safety-production incentives is obtained by convincing workers that the policy occurs in a climate of consistent support for safety.

A second illustrative result from the study can provide some insight in understanding the relationship between productivity and safety at the company level. The preceding discussion noted that productive companies in the sample tended to have low incidence rates as well—this finding is in accord with NAS *(1)*. It was further noted that policies and perceptions of policy that support safety also support production. It is instructive to ask, and attempt to answer, the question, what is it (if anything) about companies that explains the association between safety and productivity? More specifically, is it possible that there is something about organizational climate that causes companies to mine both productively and safely?

The correlation between average annual incidence rate and productivity for the sampled companies over the 1980-84 period is −0.32; that is, companies with high incidence rates tend to have low productivity. Safe companies also tend to be percieved as having comparatively consistent safety policies (correlation is 0.63) and productive companies tend to be perceived as having comparatively consistent safety policies (correlation is 0.67).

Using a statistical procedure similar to that employed in comparing the effects of stated and rated policy, the rated consistency of safety policy can be controlled statistically in assessing the correlation between incidence rate and productivity. The results suggest that net of rated consistency, the association between incidence rate and productivity becomes *positive* (0.22); that is, in comparing two companies with equal rated consistency in safety policy, the more productive one will likely be less safe.

These tentative results are interpreted as follows. At the margin, there *may* be some tradeoff between safety and productivity. *However*, the sorts of companies that are productive seem to foster a safety awareness that promotes both safety and productivity, which far outweighs the marginal tradeoff. Safe companies seem to be productive companies in part because their managements offer policies that convince supervisors and hourly personnel of a consistent posture stressing both productivity and safety.

Other additional elements, less of a policy nature, also contribute to this awareness and are discussed in the following sections.

ORGANIZATION CLIMATE AND LABOR MANAGEMENT RELATIONS

Among the variables studied were the relationships among organizational climate, labor-management relations, and safety. In general, it was found that the more positive the climate and the higher the quality of labor relations, the better the safety record. The following types of indicators were found in a setting where the climate (both labor relations and overall organizational climate) was positive:

An available and often used open-door policy to upper management (hourly interviewees said that they spoke directly with the chief executive officer or superintendent and that they got a perceived positive response);

A fair percentage of time spent underground by company management (hourly employees appreciated underground contact with upper level management, and informal conversation let others know that visits had been made);

A positive feeling and pride on the part of employees and supervisors in working for the company (focus group participants indicated that they were proud working with the company, and frequently compared notes with family members, neighbors and/or friends who worked for other companies; safety practices being an early topic of conversation);

Multiple communication vehicles were in existence in companies with a positive climate (newsletters, numerous communications on bulletin boards in the bath-house, letters sent to the home, Christmas parties for families and management, informal meetings with individuals and groups of miners).

Several labor-relations variables were reviewed through quantitative-qualitative methods. The first variable was the current status of the company and its mines in terms of unionization. Unfortunately, there were few nonunion companies able to participate, so that the direct differences between union and nonunion companies could not be examined with any confidence. The second variable was the perceived labor-relations climate as reported by both management, supervisors, and hourly labor. The third was the role and activity of the safety committee in unionized mines or its equivalent in nonunion settings.

Perceived Labor-Relations Climate

In many of the companies visited, the mines had been shut down for a year or more during the early 1980's. Once they were reopened, only some of the workers were rehired. In many of the companies, less workers were expected to produce more tonnage than before the layoffs. While technology was often improved, this production goal was not always easy to achieve. Management and long-term contract holders let the workers know that the price of equal or less productivity was shutdown. Miners are commonly the highest paid employees in the regions in which they live. When asked about the effects of this insecure atmosphere, one miner stated: "I'm one of five brothers in my family, and I'm the only one with a job. How am I supposed to feel?" Not all of the companies visited were in this fragile a condition; yet this situation was far from atypical.

How this situation affected the labor-management relations climate depended, in part, on how management presented the situation to the workforce. In one company, several managers independently noted that "each ton we dig out of the ground is one ton closer to when we close the mine." Not surprisingly, this mine was comparatively unsafe and unproductive. In other companies, the approach was very different, emphasizing not so much that "to stay open we've got to be productive", but rather "we're open *because* we're productive."

Based on the criteria noted, the labor-management relations climate was coded with considerable consistency among methods. One method was to code the focus groups for positive and negative labor-relations comments. A second was to code the interviews with managers. Interrater

reliability was 0.71. Table 9 presents safety and productivity measures separately for companies with a positive climate and with a negative labor-management relations (LMR) climate, as taken from the interviews.

Table 9.—LMR and safety committee effects on safety and productivity

	Companies	MSHA incidence rate	Production, st/h	Citations	
				Per mine	S&S
LMR:					
Positive	4	6.70	1.48	9.46	3.94
Negative	5	11.50	1.23	26.07	12.73
LMR positive:					
Active	1	2.79	1.70	3.45	1.25
Passive	3	7.98	1.40	11.45	4.83
LMR negative:					
Active	1	10.70	1.02	21.53	6.80
Passive	3	9.94	1.65	30.60	26.50
Company future:					
Positive	1	8.83	1.98	10.39	4.70
Negative	0	9.25	1.14	23.43	11.23

In accord with previous studies in the area, it was found that positive LMR climate is associated with lower incidence rates, slightly higher productivity, and lower citation and S&S citation rates. In fact, these results are nearly as strong as those relating to safety policy. Obviously, these two sets of independent variables are correlated—companies with a positive LMR climate tend to be rated as having consistent safety polices.

Safety Committee

In each of the mines, there was either a safety committee or (in nonunionized settings) a group of hourly employees who conducted safety inspections and/or audits. The safety committee commonly reflected the general labor-relations climate of the company. Where the union-management climate was strained, the committee was commonly more adversarial than in those companies where the relations were placid or highly supportive.

Overall, two types of committees could be discerned. One type was comparatively active. It was common to find an active safety committee meeting monthly with the safety director, the mine manager and the labor-relations director. It was also common to find a safety committee member accompanying an MSHA or State inspector during mine visits (along with a company staff member). These active safety committees tended to be consulted and tended to seek consultation on matters relating to maintenance, changes in mine ventilation plans, and on safety equipment. A second type of committee was more passive. Its meetings with management were more infrequent and reactive, and its members would only irregularly accompany MSHA inspectors. Consultation on change was more rare.

Two types of committees were found in both cooperative and adversarial climates. Their interactions with management, by and large, reflected climates—adversarial in negative climates, cooperative and problem-solving in positive climates.

Table 9 displays the effects of the safety committee on safety and productivity outcomes, in such a way as to highlight features of interest. In results not shown, it was apparent that the mere level of activity of the safety committee was not consistently related to safety or productivity. Rather, the effects of safety committee activity depend on the overall LMR climate. While the sample sizes make generalization hazardous, the results are suggestive. Even where the LMR climate is positive, if the safety committee is passive, little difference from a negative LMR climate is observed in terms of incidence rate (7.98 average annual rate as compared with 10.7 or 9.94). However, a positive climate in conjunction with an active safety committee shows strong effects on safety (average annual incidence rate of 2.79). What is observed is a synergistic effect of participation and supportiveness, similar to that found by Sanders (*2*).

The results for productivity are even more striking. Where the LMR climate is positive, an active safety committee is associated with *higher* production; where the climate is negative, an active safety committee is associated with *lower* production.

The effects of safety committee activity and LMR climate on citation rate and S&S citation rate are more straightforward. Where LMR climate is positive, fewer citations are found; where the safety committee is active, again fewer citations are observed. It is suspected that where a positive LMR climate and an active committee are present, conditions contributing to citation rate are not allowed to develop, and hazards are dealt with as they are discovered.

A final item on organizational climate bears mention, and is shown in table 9. On the basis of interviews and focus groups, it was possible to assess prevalent opinion within the company on the company's financial future. Coded separately from focus groups and interviews, a high degree of unanimity was achieved. As the results suggest, when the company's future is seen as positive, productivity and safety results are positive as well. Whether these results reflect a cause-and-effect relationship will be examined in the final year of this study.

SAFETY DEPARTMENT ORGANIZATION AND STAFFING

Several previous studies have commented on the role of the safety department in supporting a climate of mine safety. Unfortunately, as with several previous elements, the role of the safety department is pervasive but not particularly systematic. All of the companies in the sample had safety personnel at mine and company levels. However, many of the companies had experienced cutbacks, especially in training personnel. These cutbacks had two implications. First, where training and safety personnel were in the same department, it was unclear whether safety personnel were affected. Second, even where training and safety were organized separately, safety personnel were increasingly taking on responsibilities, such as escorting MSHA inspectors, which had previously been handled by training personnel. Thus, attention to accident investigations, to special training, and to safety implications of equipment and maintenance may have suffered.

In terms of personnel, the educational qualifications of safety personnel seemed less important than underground experience in creating credibility with the workforce. There is, moreover, impressionistic evidence that the informal prestige of the safety personnel was higher in relatively safe, productive mines, although this was, surprisingly, not uniformly the case. In companies where the safety department had relatively low prestige, however, there tended to be another well-placed advocate for safety in top management.

SUMMARY AND CONCLUSIONS

This paper attempts to identify management practices in underground coal mining that can be linked to safety and productivity outcomes, based on a study of 10 mining companies and their operations. The results should be considered tentative and provisional, since the study was midway through its data collection period at the time this paper was prepared. Nonetheless, the findings are suggestive of future directions for researchers and practitioners alike.

Companies that were successful at mining coal safely tended also to mine at high rates of productivity. To accomplish these results, mine managers used a variety of techniques, some of them unique to the company, some of them uniform across companies. Successful companies frequently had one or two vehicles they utilized to press home safety. While the specific vehicles varied by company, they shared the characteristics of (1) identifying complete sequences of activities that were broadly participative, and which could be implemented, monitored, and followed up; (2) being advocated forcefully by a well-positioned company official; and (3) frequently being seen as unique to and invented by the company.

Characteristics of completeness and advocacy (characteristics 1 and 2) were also true of the specific policy elements that were identified as being effective at supporting safety and productivity. These included safety-productivity incentives, accident discipline policies, information distribution, and formal investigations following accidents. There was some evidence that the effects of safety-production incentives were to both improve safety and to suppress the reporting of minor injuries—the latter tendency should, obviously, be monitored with care. There were two other programs that should be implemented with care—rehabilitation programs and repeater programs. These tended to be viewed with much suspicion by the workforce and tended to detract from a consistent, clear safety policy.

There was evidence that the major safety effects of these policies were accomplished by convincing the mine workforce that management was clearly and consistently supportive of safety. Absent this awareness, the positive effects of management policy, while still present, were much reduced. In fact, tentative evidence was presented suggesting that the common feature explaining the tendency for safe companies to be productive ones was the capacity of management to convince the workforce of a consistent clear posture supporting safe but high production. Labor-management relations and organizational climate contributed to this understanding. Where LMR was positive, production and safety were higher. Safety committees tended to focus on both the positive and negative aspects of the LMR climate. Where the climate was positive and the committee active, safety and production results were positive; where the LMR climate was negative and the safety committee was active, production and, to some extent, safety suffered. Finally, both safety and production suffered when the company's future was uncertain or bleak.

Results on the staffing and organization of the safety department require further analysis. In the current economic climate, there have been substantial cutbacks in the training function in particular, with increasing reliance on contractor-provided training. There is no evidence of negative safety results, but this topic will be monitored carefully.

This paper can be seen as placing an unfair burden on mine managers. Already strapped by an uncertain market for coal, mine managers are responsible both for seeing to the financial future of their companies and their safety results as well. In fact, however, the findings make clear that safety is a shared responsibility, and that when this responsibility is shared and reinforced, it benefits not only safety, but also productivity. Management is responsible for setting and reinforcing safety policies, but these policies can only be successfully carried out when there is widespread agreement on the importance of safe productive operation, and a shared commitment to achieve it.

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MINER ABSENTEEISM: CONSEQUENCES, CAUSES, AND CONTROL

By Robert H. Peters[1]

ABSTRACT

This paper presents a summary of in-house and contract research the Bureau of Mines has sponsored to determine the consequences, causes, and control of coal miner absenteeism. Several significant problems, especially safety, associated with absenteeism among underground coal miners are described, and a conceptual model of the factors that cause absenteeism among miners is presented. The highlights of two empirical studies of coal miner absenteeism are discussed, and several strategies for improving miner job attendance are presented.

INTRODUCTION

Although estimates of the rate of absenteeism in the mining industry vary, most sources suggest that it is high, relative to other industries. Based on attendance data collected in May 1978 and May 1980, the U.S. Bureau of Labor Statistics reported that, among all U.S. nonfarming industries, mining was the highest in terms of the proportion of hours lost to absences (*53, 56*).[2] An analysis of absence data presented by Goodman (*17*) reveals the following statistics concerning absence rates during 1982 at 11 relatively large underground coal mines with unionized labor: Total absenteeism across these 11 mines averaged 12.1 pct.[3] This total is composed of sanctioned absences (5.8 pct), nonsanctioned absences (2.2 pct), and absences due to sickness and injury (4.1 pct).

Given current high rates of unemployment in the mining industry, absence rates in the mid-1980's are probably not as high as they were in the preceding decade. The U.S. Bureau of Labor Statistics May 1985 survey found that absenteeism in the mining industry was 3.6 pct, which was lower than the corresponding percentage for 1980 by 1.8 percentage points (*55*). Although the problem of absenteeism is not as widespread today as it once was, it still exists, and will continue to come back to haunt the mining industry from time to time, until mine managers learn better methods for controlling it.

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[2]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

[3]This rate was calculated as follows: total days absent/number of days scheduled to work × 100. Unlike the U.S. Bureau of Labor Statistics, Goodman includes graduated vacation days in the numerator. He defines absences as any days when the *mine* was scheduled to operate, but the individual did not come to work.

Although there appear to be no published estimates of the cost of absenteeism in the mining industry, one can safely assume that, based on the estimated rates of absenteeism, the costs are significant. In 1976, the labor relations vice president for one of the largest coal companies reported that his company was carrying an extra 5 pct of labor to allow it to cope with absenteeism (*60*).

It is inevitable that members of underground coal mining crews will occasionally be absent. Sometimes the crew will work without a replacement, but usually someone is assigned to fill in for the missing miner. In either case, safety and production problems become more likely. Temporary replacements for regular crew members are relatively unfamiliar with the habits of the people who work in the crew, and the physical conditions and equipment in the section.

Because they are unfamiliar with key aspects of their work environment, temporary replacements often either do things or fail to do things that increase accidents and that can reduce productivity. This problem is especially important in underground coal mining because it is a very hazardous work environment, and because the work performed by miners is very interdependent.

In order to keep attendance as high as possible, it is important to understand as much as possible about what causes miners to be absent. Understanding the primary causes of absenteeism is a prerequisite for deciding which of several strategies is going to be most effective for maintaining a high level of attendance. Therefore, the Bureau of Mines conducted the research study presented in this paper primarily to learn more about the reasons for coal miners' absences.

CONSEQUENCES OF MINER ABSENTEEISM

Most of the literature dealing with the consequences of miner absenteeism focuses on the effects that absenteeism has on mine safety and productivity.

EFFECTS OF ABSENTEEISM ON SAFETY

A variety of sources have noted that absenteeism threatens miner safety. The Theodore Barry report (*54*) notes that absenteeism leads to short-crew sections, with crew members forced into unfamiliar operations and tasks. The report says

> In short-crew situations, section foremen often request that one or more crew members from the previous shift "double-back", i.e., work a second consecutive shift. Fatigue is the natural result of a 16-hour period of hard physical activity, and fatigue and accidents are highly correlated in any industrial activity.

Snyder (*51*) notes that another common way to cope with absent mining crew members is for the supervisor to fill in for the missing crew member. She cites this practice as one of the reasons that the rate of fatal accidents suffered by supervisory personnel in the coal industry is significantly higher than the corresponding rate for mine production workers. She points out that supervisors who do this are not as familiar with the temporary work, and tend to be more likely to get injured while doing such jobs:

> A foreman who performs a task once in a while—say, to fill in for a crew member who's sick—is more likely to have an accident while doing it than the miner who does the job every day. The foreman is not as familiar with the job. The safe procedures don't come automatically. Even a foreman who used to do the task regularly is liable to be "rusty" when returning to it on an occasional basis.

She also notes that when supervisors are engaged in production work, they do not have as much time to look out for the safety of other miners.

Wilkinson (*60*) cites several mining company and union officials who have claimed that miner absenteeism produces unsafe working conditions. The United Mine Workers of America (UMWA) has even tried sending union representatives out to the homes of poor attenders to discuss the importance of good attendance.

The Mine Safety and Health Administration (MSHA) recently performed a study of the differences between underground coal mines with high versus low rates of injuries (*11*). It was observed that "absenteeism was much more of a problem at high rate mines than at low rate mines." The average rate of absenteeism at the 21 high-rate mines was approximately 16 pct. On the other hand, at the 19 low-rate mines, the average rate was approximately 8 pct.

The first empirical study of the effects of miner absenteeism on accident rates was performed by Goodman (*17*). Data were collected from a sample of miners at 19 underground coal mines. The data consisted of mine daily attendance records, accident records, and detailed interviews with approximately 50 miners from each mine. It was found that crews with poor job attendance consistently experienced slightly more accidents than other crews. Goodman attributes the greater incidence of accidents in these crews to the tendency for replacement workers to be relatively unfamiliar with their temporary jobs.

EFFECTS OF ABSENTEEISM ON PRODUCTIVITY

It is generally acknowledged that absenteeism adversely affects a mine operation's productivity. In describing the processes by which absenteeism influences productivity, Adkins (*2*) notes

> First of all absent workers simply don't produce much coal. In more indirect paths one can see that absenteeism can both increase safety problems and decrease the general skill level of the crews. Deteriorating skill levels lower production and increase maintenance and down-time problems. Absenteeism leads to labor/management relations problems, frequently arising from attempts to discipline absent workers, which in turn lowers the productivity of both labor and management.

Goodman (*20*) provides empirical evidence concerning the effect of crew size on productivity. He analyzed data from 81 mining crews at six underground coal mines using the number of tons of coal removed by a mining crew during a shift as the criterion variable. After using multiple regression analyses to statistically partial out the effects of other factors (differences in equipment, physical conditions, etc.), crew size consistently emerged as a statistically significant variable in accounting for variation in the criterion variable. This strongly suggests that absenteeism, which results in crews with fewer than the normal number of persons, results in significantly lower productivity. How much lower? At one of the mines, the marginal impact of a missing crew member on daily productivity was 6.3 st in development sections, and 11.8 st in sections engaged in pillaring. Of the six mines examined, the marginal impact of a missing crew member ranged from as low as 1 st to as high as 17.5 st.

In conclusion, it appears that miner absenteeism is generally considered to be an important cause of accidents and low productivity. However, with the exception of Goodman (*17, 20*), there appears to be very little empirical evidence concerning these assumptions.

CAUSES OF MINER ABSENTEEISM

As was true about research on the consequences of miner absenteeism, there appears to be considerable speculation about the *causes* of miner absenteeism, but little empirical evidence. Only two empirical studies of the causes of miner absenteeism have been performed (Goodman (*17*) and Peters and Randolph (*44*)).

As previously mentioned, Goodman collected data from a sample of miners at 19 underground coal mines. The data consisted of mine daily attendance records and detailed interviews with approximately 50 miners from each mine. Goodman's (*17*) findings concerning the types of factors that appear to contribute to miner absenteeism include the following:

Illnesses and injuries are the most commonly cited causes of absence.

Off-the-job activities that miners need or want to do (e.g., family, hunting) are also commonly cited.

Negative job factors that might cause miners to avoid work are **not** frequently mentioned sources of absences.

Miners holding down another job are consistently absent more than their coworkers.

An organization's absence control policy and the degree to which that policy is consistently implemented within the workforce is a significant determinant of attendance.

Most miners do not feel highly pressured to produce—but those who do feel such pressure have higher absence rates.

Demographic factors, such as age, seem to be related to absenteeism. However, the effect of demographics on absenteeism varies greatly among mines.

Most miners report that they would rather have more time off than more money. This suggests that the desire for time away from work is one of the more important forces contributing to absenteeism.

Based on prior studies of absenteeism and what is known about the coal mining industry, Peters and Randolph (*44*) developed a model of factors that appear likely to influence coal miners' rates of absenteeism (see figure 1). The predictions from this model were empirically tested on a sample of 63 underground miners from a western Virginia coal mine. Miner absenteeism rates during a recent 12-month period were used as the criterion variable, and data on miners' demographic characteristics and attitudes about their work were used as predictors.

Nine different indexes of absenteeism were constructed from the attendance data. Using multiple regression analyses, a model similar to the one portrayed in figure 1 was used to account for variance in the nine indexes of absences. Although the model usually accounted for a substantial amount of the variance (ranging for 44 to 79 pct) in the nine indexes of absenteeism, it emerged as a statistically significant ($p < 0.050$) predictor of only one absenteeism index. This absenteeism index measured the *number of consecutive work days* that miners were away from their job whenever they used days that the UMWA contract refers to as graduated vacation days or paid personal days.[4] Absences due to these reasons were analyzed separately because, in contrast to absences caused by illness or injury, absences for these reasons are much more likely to be within the miner's ability to control.

[4]See Peters and Randolph (*44*) for a complete discussion of the other indexes and how they are analyzed.

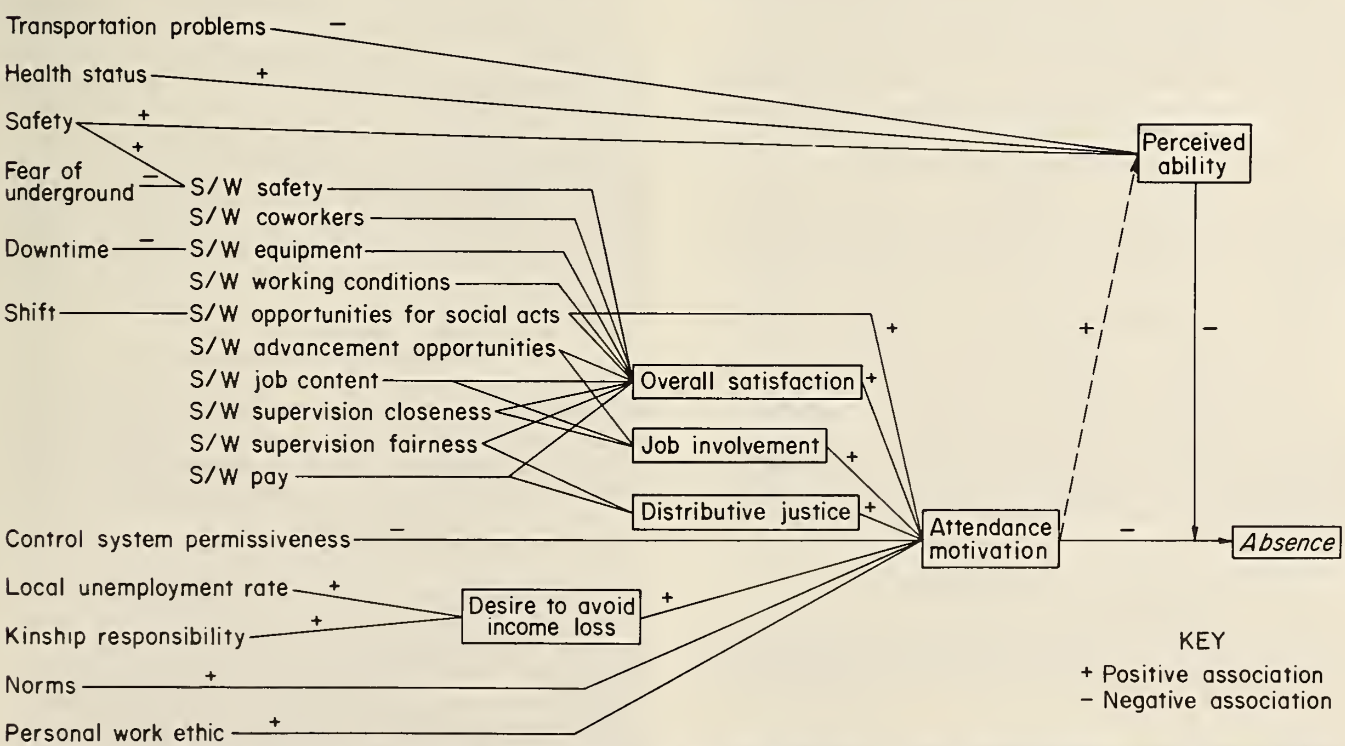

Figure 1.—Absenteeism model. (S/W—satisfaction with. The hypothesized relation between the variables "Shift" and "Satisfaction with opportunities for social acts" is that miners who work daytime shifts are more satisfied with their opportunities for participating in social activities than those who work other shifts.)

Two variables were found to be statistically significant predictors of the duration of absences taken as graduated vacation leave or personal days: *level of satisfaction with supervisor* and *level of satisfaction with pay*. This means that, when they had a choice about being absent, miners who were relatively dissatisfied with their pay and/or the way their supervisor treated them, were inclined to stay away from work for longer periods of time than miners who were more satisfied with their pay and/or the way their supervisor treated them.

Why would miners who are dissatisfied with their pay and/or their supervisor tend to be absent for relatively long spells? The answer is not exactly clear. One explanation, derived from equity theory (*1*), is that these long spells of absence may stem from a reluctance to resume participating in an unfair employment relationship. Employees who believe that their employer or supervisor is unfair (and who cannot find employment elsewhere) are likely to experience negative affective reactions, such as feelings of frustration or anger. Employees who are having such undesirable reactions may experience temporary relief from them whenever they are away from work. Because returning to work is associated with an intensification of these undesirable feelings, these employees may tend to stay away from work for relatively long periods of time.

A MODEL OF THE CAUSES OF MINER ABSENTEEISM

Much research has been performed on the causes of employee absenteeism among nonmining employees. Through use of the findings from prior research on the absenteeism of miners and other types of employees, a conceptual model of the factors that contribute to absenteeism among miners was generated (fig. 1).[5]

Predictions regarding the direction of the association between the variables in the model are indicated by plus and minus signs (fig. 1). Miner attendance behavior is hypothesized to be influenced most directly by perceived ability to attend and motivation to attend.

PERCEIVED ABILITY TO ATTEND

Miner ability to attend is obviously an important factor in actual attendance. However, perceived ability may be more important than actual ability. That is, a snowstorm or a bad cold may or may not limit one's ability to come to work. What is important is how the individual treats the event and how he or she interprets its impact on ability to attend. This is why the model contains a dotted line going from attendance motivation to perceived ability to attend. In addition to attendance motivation, other important determinants of perceived (and actual) ability to attend are transportation problems, health status, and safety.

ATTENDANCE MOTIVATION

The model identifies eight direct determinants of miner attendance motivation: overall job satisfaction, satisfaction with time for social activities, job involvement, distributive justice, absenteeism control system permissiveness, desire to avoid income loss, attendance norms, and personal values. Each of these are discussed in the following sections.

Overall Job Satisfaction

Although many researchers have found that job satisfaction is related to attendance, Goodman's (*17*) study suggests that job satisfaction may not be an especially good predictor of coal miner attendance. The relationship between these two variables should be further investigated. Therefore, it is hypothesized that job satisfaction is positively related to miner attendance motivation. For practical as well as theoretical reasons, it would be valuable to know which specific facets of job satisfaction are most strongly related to absenteeism. Therefore, the following variables are also included: satisfaction with safety, with coworkers, with equipment, with working conditions, with opportunities for social activities, with advancement opportunities, with job content, with supervision, and with pay.

Satisfaction With Opportunities for Family-Social Activities

A significant portion of the time most underground coal miners spend at work is during evening and night shifts. Because miners who must work these shifts may have limited opportunities to do things they enjoy with their family and friends, they may be especially likely to be absent from time to time so that they can take part in such activities. The rotating shifts used by some mining companies can also be disruptive to a miner's social life. Therefore, it is hypothesized that those who work nondaytime or rotating shifts (1) have lower levels of overall job satisfaction, and (2) have lower levels of motivation to attend work.

Job Involvement

Job involvement has been found to be positively related to attendance. According to most definitions, the key determinants of job involvement are aspects of job content, supervision, and career advancement opportunities. To the extent that the job involves work that allows the miner to feel that he or she is making important contributions to the organization, to experience a sense of personal achievement, and to make use of his or her skills and abilities, the miner will be involved in his or her job. To the extent that miners are supervised in such a way that they are typically allowed to influence what goes on at their worksite, set their own work pace, actively participate in decisions about their work, and use creativity in solving problems, they will be involved in their job. To the extent that miners perceive that their career advancement opportunities with their current employer are good, (i.e., that

[5]A summary of the absenteeism research findings for mining and for nonmining employees is presented in Peters and Randolph (*44*). The report also contains a more detailed discussion of the variables in the absenteeism model presented in this paper.

they are sufficiently competent and successful to be given the opportunity to perform more important and more difficult jobs in the future) miners will be involved in their current jobs. Therefore, it is hypothesized that (1) miner satisfaction with job content, freedom from close supervision, and career advancement opportunities are all positively related to job involvement, and (2) the greater the miner job involvement, the greater is the motivation to attend work.

Distributive Justice

Equity theory, as originally proposed by Adams (*1*), considers employee perception of fair treatment by the employer to be a major determinant of the motivation to make contributions of time, energy, ingenuity, etc., to the job. The theory holds that one of the ways employees may respond to actual or perceived unfair treatment is to reduce their job contributions. One obvious way to accomplish this reduction is to attend work less often. Therefore, it is hypothesized that a significant determinant of miner attendance motivation is the extent to which they perceive that they are treated fairly by their employer, i.e., the degree to which distributive justice is perceived to exist in the employee-employer exchange.

One important determinant of distributive justice is miner perception about the adequacy of wages, benefits, and other economic rewards the employer provides. Another important determinant is the degree to which miners perceive that their supervisor allocates work assignments, resources, and various nonmonetary rewards and punishments in an equitable manner. Therefore, it is hypothesized that miners' perceptions of distributive justice are determined by their satisfaction with their economic rewards and the degree to which they perceive that their supervisor treats them fairly.

Absence Control System Permissiveness

Absence control systems involve those policies and procedures used by the organization to encourage attendance. The permissiveness is the degree to which absenteeism is accepted by the organization. The central idea of this concept is frequent absence without consequence (*42*). An organization or subunit in which numerous casual absences result in little or no apparent adverse consequences would be highly permissive toward absenteeism. Empirical support for the hypothesized direct causal relationship between permissiveness and absenteeism has been reported by Seatter (*50*), Rhodes and Steers (*47*), Winkler (*61*), and Popp and Belohav (*46*). Therefore, it is hypothesized that the permissiveness of the mine's absence control system is positively associated with absenteeism.

Desire to Avoid Loss of Income

Miners differ in the extent to which they desire to avoid losing income. The strength of this desire is hypothesized to be positively related to their attendance motivation. Two determinants of miner desire to avoid income loss are the local unemployment rate and kinship responsibilities.

Local Unemployment Rate

Economic and job-market conditions often place constraints on an employee's ability to change jobs. As a result, in times of high unemployment, there may be increased pressure to maintain a good attendance record for fear of losing one's job. Several studies have found an inverse relationship between changes in unemployment levels and subsequent absence rates (*6-7, 10*). Therefore, it is hypothesized that local unemployment rates are positively related to miner desire to avoid income loss, and to attendance motivation.

Kinship Responsibility

Another determinant of miner desire to avoid income loss is the degree to which miners are responsible for supporting family members or other dependents. In contrast to single miners with fewer financial responsibilities, miners who must support a family are probably going to be less willing to take the chance of losing some of their pay (or getting fired) because they take off work for reasons that the company considers unexcusable. Therefore, it is hypothesized that kinship responsibility is positively related to miner desire to avoid income loss, and to attendance motivation.

Norms

Several authors have suggested that another important determinant of attendance motivation is the degree to which the immediate work group views one's absences from work negatively (*14, 27, 36, 52*). Therefore, it is hypothesized that miner attendance motivation is positively related to the degree to which the crew views absences among its members negatively.[6] Although it has not been formally tested, it would also seem likely that miner attendance motivation is significantly affected by the norms of miners' families, relatives, and close friends regarding the importance of job attendance.

Personal Values

Finally, the miner's personal value system may be an important determinant of job attendance. Prior research suggests that a strong personal work ethic is closely related to attendance (*12, 15, 26*). Therefore, it is hypothesized that miner attendance motivation is positively related to the degree to which miners have a strong personal work ethic.

It is also important to consider personal values concerning *nonwork* activities. Some absence may be attributable to the value miners place on their nonwork activities. In his study of the Rushton Mine, Goodman (*16*) found that, although they view their work as important, miners usually did not feel that their job was the central part of their life; home and other nonwork activities were more central. This observation suggests that the values miners place on nonwork interests (e.g., hunting, hobbies, family activities) may be an important reason for some of their absences.

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[6]However, for various reasons it has been argued that the amount of peer group pressure on miners to attend work is minimal (*2, 51, 56*).

STRATEGIES FOR REDUCING ABSENTEEISM

In general, strategies for reducing absenteeism should fit the specific causes of absenteeism. The causes of absenteeism stem from the employee's inability or unwillingness to attend work. However, before proceeding to discuss potential solutions to each of the specific causes, one generic strategy for preventing high absenteeism will be discussed; i.e., improving procedures for hiring new employees.

IMPROVING HIRING PROCEDURES

Research by Breaugh (*8*) and Keller (*30*) suggests that prior attendance records could be a very simple but effective device for evaluating prospective new employees. Both studies found that employees' prior absenteeisms were a statistically significant predictor of their future absenteeism.

Realistic job previews can be a complementary mechanism to good selection practices. It is assumed that a person who chooses to accept an employment offer based on a complete and realistic job description is likely to have greater commitment to that job. The goals of the preview are (1) to ensure a good match between the capabilities and needs of the applicant and the requirements of the job and company; and (2) to be sure that the applicant has a good picture of both the positive and negative aspects of the job (*58*). This seems particularly important in the mining context if the applicant has no underground mining experience. Although job previews have been empirically demonstrated to reduce turnover (*58*), there appears to be no research concerning their effects on attendance.

As previously mentioned, it is important to consider the specific causes of employees' absences. These specific causes can be thought of as stemming from the employee's inability or unwillingness to attend work.

OVERCOMING INABILITY PROBLEMS

The major reasons employees are unable to attend work are physical health problems, mental health problems, occupational hazards, and transportation problems. The remainder of this section presents strategies for reducing each of these types of barriers to miner job attendance.

Physical Health Problems

Illness is widely recognized as the most important cause of absenteeism (*22-24, 38*), accounting for from one-half to two-thirds of all employee absence (*40*). In the mining industry, injuries are a particularly important cause of employee absence. According to MSHA, injuries accounted for an average of 1.42 pct of the total days of work missed by the employees of underground coal mining operations during the years 1980-84 (*57*). The percentages per year ranged from 1.29 to 1.59 pct. Of the various types of work-related injuries suffered by miners, back injuries account for a far greater amount of lost time than any other single type. Back injuries account for approximately 31 pct of all the workdays underground coal miners miss because of work-related injuries (*43*). Thus, it appears that illnesses and injuries account for a substantial portion of the total time coal miners miss work.

A worker who is more susceptible to illness or injury, or one who has certain chronic illnesses or injuries, is more likely to be absent. If the source of absenteeism was from personal health problems, there could be a variety of possible strategies to deal with this cause. Better selection procedures could eliminate chronic cases. Making in-house medical services, special testing programs (e.g., for hypertension), and health education programs available is another possible response to personal health problems. Unfortunately, other than a study by Hedja, Smola, and Masek (*25*), there is little or no empirical evidence concerning the effectiveness of this type of strategy for miners. (Hedja, Smola, and Masek found that influenza vaccinations and daily doses of vitamin C produced a significant reduction in absences due to illness at Czechoslovakian coal mines.)

Mental Health Problems

Mental health problems include chronic emotional problems (e.g., depression) and other forms or symptoms of emotional illness, such as alcoholism and drug abuse. A recent study indicates that these causal factors do appear among employees in the coal industry, and they do seem to have some impact on absenteeism and performance (*18*).

Selection and employee assistance programs (EAP's) are the most traditional methods for dealing with mental health problems. The first strategy attempts to improve the quality of those mechanisms that screen out workers who have mental health problems that interfere with job performance. EAP's are designed to provide diagnosis, referral, treatment, and followup for workers with these types of problems. There are many types of EAP's. While some are broad brush, others are specific (e.g., alcoholism); some only provide diagnostic and referral services, and others also include treatment (see Goodman (*18*) for further details). The assumption behind these programs is that the removal of these emotional problems will enhance worker attendance, safety behavior, and productivity.

Occupational Hazards

Because accidents are an obvious cause of one kind of absenteeism, an effective company safety and health program is an important deterrent to absenteeism. In two studies it has been found that workers who feel they are being exposed to dangerous or unhealthful working conditions have substantially higher absence rates than other workers (*3, 37*). Allen (*3*) argues that, not only do hazardous working conditions cause absences directly, i.e., through lost-time injuries, such conditions also cause high absenteeism indirectly—employees wish to avoid their workplace because it is perceived as a threat to their safety and health. For a discussion of the characteristics of effective safety programs for the mining industry, see reference 45.

Transportation Problems

Factors such as driving distance to work, bad roads, weather, or other transportation problems, are related to absenteeism. Such problems are common in the mining

industry. Miners are often located in isolated rural areas and must drive long distances to get to work. Some companies in mining and nonmining industries have provided transportation (e.g., company buses) to reduce absenteeism. Unfortunately, there are no cost-benefit analyses to indicate the effect of these procedures.

Thus far, only the reasons employees are unable to attend work have been considered. The next section discusses specific reasons why employees may be unwilling to attend work.

OVERCOMING MOTIVATIONAL PROBLEMS

As discussed earlier, research suggests that there are many reasons why employees who are able to attend work are, nevertheless, sometimes unwilling to attend work. It is important to consider the sources of their unwillingness. The sources can be either positive features of the nonwork environment or negative features of the work environment. Goodman's (*17*) study suggests that the most important causes of miner absenteeism are generally attractive features of the nonwork environment, and that in general, negative features of the work environment are not responsible for miner absenteeism. The remainder of this section presents strategies for increasing miner motivation to attend. These strategies are giving feedback, training for supervisors and employees, job design, and incentive programs.

Giving Feedback

Measuring absenteeism and posting attendance information may reduce absenteeism. Latham and Napier (*35*) state that

> from the standpoint of motivation, measurement in itself may be the most highly effective, underused, and deceptively straight-forward approach available for increasing attendance. The process is effective because "what gets measured gets done." The simple act of putting a measure on something focuses attention on that area.

They report several studies that used publicly reported attendance information to significantly decrease absenteeism. Latham and Napier (*35*) admit that this intervention requires some increase in clerical-computer costs, but claim that these costs are likely to be trivial in comparison to the gains realized from significantly higher attendance rates.

A study conducted at Parkdale Mills, Inc., nicely illustrates the effectiveness of this appraoch (*39*). Prior to the study, people who were absent were reprimanded. Those who had good attendance records received no comments. A 15-week baseline showed that attendance averaged 86 pct. At the end of the baseline period, a daily attendance chart was placed in the work area. A blue dot was placed on the chart beside the name of each person who was on the job. A red dot was placed beside the name of each person who was off the job. A person who had been absent was welcomed back to the job by the supervisor. No oral or written reprimands were given. The supervisor maintained this graph daily. In addition, he posted a weekly attendance graph that showed the percentage of people who attended the job each day. From a baseline average of 86 pct, attendance averaged 94.3 pct for the following 9-week period. The cost of the materials for this program was less than $10.

Training

Training can be an important strategy for reducing absenteeism. Training for this purpose has been conducted for supervisors and for employees.

Training for Supervisors

The Bureau of National Affairs (BNA) (*9*) survey found that, although supervisors in 82 pct of the firms are charged with maintaining daily attendance records, only 42 pct of the companies train supervisors in absence control. The BNA report indicates that the firms that train their supervisors on this topic provide information on techniques for counseling employees, recognizing attendance problems, and methods for handling verbal reprimands and other disciplinary procedures. Although a few companies educate their supervisors in absence control through one-to-one consultation with a personnel department staff member, most provide the information through supervisory meetings, seminars, or films.

One employer's approach to supervisory training in absence control includes a booklet describing the supervisor's role in sick leave administration. The booklet describes types of health problems, circumstances for which sick leave may be taken, and instructions for processing sick leave requests. A major intent of this publication is to provide a set of uniform guidelines so that all supervisors will be following the same standards in making sick-leave decisions.

Latham and Napier (*35*) state that supervisors are a key to keeping attendance rates high.

> It is they who should be responsible for keeping attendance records, so that a high attendance rate can be rewarded and a low attendance rate can be corrected. This is not likely to be done if the attendance data are buried in time cards, if the supervisor is continually second-guessed by others on judgments regarding the "why's" underlying an absence, if the supervisor is not trained in how to focus on problems rather than personalities, and if the rules regarding attendance are vague and subject to many interpretations.

There is very little empirical evidence concerning the effects of supervisory training on absenteeism. However, on a commonsense basis, training the supervisor to deal with absenteeism seems an important strategy in reducing absenteeism because the supervisor is the person who deals first with the absentee problem. Research by Wexley and Nemeroff (*60*) suggests that having supervisors participate in role-playing exercises related to violations of organizational attendance rules can result in decreased absenteeism.

Adkins (*2*) also stresses the importance of making sure that supervisors understand how to respond to their subordinates' absenteeism.

> When a problem individual begins to show up in the records, someone who knows him (most likely the immediate supervisor) should talk with him about it face to face before he gets letters on company stationery. The latter only breed hostility and resentment. Consistent and even-handed administration of the program, particularly the disciplinary aspects, is likely to be more important to worker acceptance than are the details of the program.

Training for Employees

Research on an orientation training program developed by Rosen and Turner (*48*) suggests that it is possible to achieve attendance rates for "hard-core hires" that are as good as the rates for stable employees, i.e., those who had met normal hiring criteria. Goodman (*17*) claims that it is important to supplement orientation training with *periodic* training about the absentee control plan. He claims that discussing the plan in an orientation session may have a short-term effect, but will not affect absenteeism over time.

Job Design

There is considerable research on the impact of job characteristics on worker satisfaction and absenteeism. One of the more important determinants of employee motivation to attend appears to be level of job involvement (*4, 28-29*). According to Katz and Kahn (*29*), in order to arouse and maximize job involvement, the job must provide sufficient variety, sufficient complexity, sufficient challenge, and sufficient exercise of skill to engage the abilities of the employee. Katz and Kahn argue further that job involvement occurs to the extent that employees (1) participate in important decisions about group objectives, (2) contribute to group performance in a significant way, and (3) share in the rewards of group accomplishment.

In Kanugo's (*28*) review of research on the consequences of job involvement, she concludes, "On the basis of the existing evidence, it seems reasonable to assume a negative relationship between job involvement and absenteeism, but the evidence is limited to only a few studies."

Job enrichment and the creation of autonomous work groups appear to be effective strategies for increasing job involvement. According to Filley, House, and Kerr (*13*), job enrichment occurs when any of the following types of changes occur: employees are supervised less closely, given greater influence over their environment, given greater freedom to control their own work, and given greater opportunity to plan for the future and to participate in planning matters that affect their jobs. In their review of attempts to use these strategies in various types of organizations, Goodman and Lawler (*19*) note that there has been a trend toward experimenting with new forms of job and organizational design over the past 10 yr, and that these interventions usually result in lower levels of absenteeism.

Job enrichment is generally thought to result in greater intrinsic motivation to work. Adkins (*2*) believes that the key to improving miner attendance is through increasing intrinsic rewards.[7] He writes, "Intrinsic rewards that serve to improve the quality of work life and level of job satisfaction are more likely to improve attendance than are strategies based on extrinsic rewards or punishments."

The primary effect of an autonomous work group is to increase the employee's opportunity to participate in decisions affecting his or her job. Goodman (*16*) conducted an empirical evaluation of the effects of an autonomous mining crew structure at the Rushton coal mine. He found that, in comparison to control group crews (who kept the traditional pattern of centralized decisionmaking), absenteeism was reduced to a significantly lower level in the autonomous mining crews. This suggests that increasing the degree to which miners are allowed to participate in decisions affecting their job can significantly improve their attendance.

Incentive Programs

Three general types of incentive programs have been used to reduce absenteeism: positive reinforcement programs, negative sanctions programs, and mixed programs—ones that used positive and negative incentives.

Positive Reinforcement Programs

Positive reinforcement programs provide some reward for lower absenteeism. Steers and Rhodes (*52*) review of research on these programs indicates that reinforcers such as bonuses, participation in a lottery, participation in a poker hand, food credit reimbursement for unused sick leave, and desirable work schedules can lead to a reduction in absenteeism. While there are other programs using positive reinforcement that did not lead to a reduction in absenteeism, the majority of the empirical evidence supports the effectiveness of positive reinforcement programs.

One criticism of these programs is that they are not always cost effective. Kempen (*31*) notes that they are often not cost effective because all the perfect or near-perfect attenders receive the money (or reward), even though they cannot improve their attendance. To avoid this cost, Kempen suggests that two questions be asked: (1) What privileges would people like to have that they do not have now? (2) What do they find irritating or aversive in the work setting? The answers to these questions provide a list of possible rewards for reinforcing attendance that may not be costly to the organization. Examples of nonmonetary privileges for good attendance that have been tried include freedom from punching time clocks, 1 or 2 excused days off without pay, and immunity from disciplinary action for a year related to absence taking.

Negative Sanctions

Programs based on negative sanctions are built around absentee control plans. Control plans usually specify stages, levels of absenteeism permitted, penalties, and continuous attendance necessary to work oneself off the absentee control plan. Basically these plans identify a series of stages of varying forms of punishment. For example, absenteeism at a particular level would lead to a warning letter. Subsequent levels of absenteeism would lead to a suspension. Continued absenteeism would lead to dismissal.

According to Steers and Rhodes (*52*) and Baum (*5*), the literature is characterized by divided opinions and conflicting findings concerning the efficacy of sanctions in reducing absenteeism. Much of the opposition to the use of sanctions is based on two grounds: (1) behavior modification techniques based on positive reinforcement of desired behaviors (coming to work regularly) are more suitable and effective in dealing with absenteeism; (2) sanctions based on the use of disciplinary procedures (punishments) tend to produce undesirable side effects that are as objectionable as the behavior of primary interest. For example,

[7]Intrinsic rewards result directly from effort and effective performance (usually these take the form of enjoyment with the effort itself or satisfaction with goal attainment). Extrinsic rewards are those controlled by others.

Nicholson (*41*) found that rigorously enforced sanctions caused workers to resort to longer, medically related absences to escape the consequences of the disciplinary system; the overall level of days lost was not changed by the clampdown.

In contrast, Baum (*5*) found that the strict enforcement of the control policy had no discernible effect on either long-term illnesses or contractual absences. A well-designed study by Baum (*5*) suggests that negative sanctions can significantly improve the attendance of chronically absent employees. The study employed a nonequivalent control group design since it was not possible to randomly assign subjects to the treatment and control groups. Absenteeism was defined as the number of days the worker failed to report to the job when work was scheduled excluding long-term illnesses and contractual absenteeism.

In the experimental group, management used the following six-step procedure in all cases of unauthorized absenteeism: (1) detailed attendance records would be kept by the worker's supervisor, (2) written excuses from legitimate outside sources would be required for unauthorized absences, (3) questionable excuses would be independently investigated, (4) management would personally counsel all workers with unauthorized absences, (5) the existing progressive discipline system would be used to penalize excessive absenteeism, and (6) updated discipline and attendance records would be maintained on all workers. The managers in the two comparison departments continued with the existing attendance policy that simply delegated the responsibility for attendance control to the immediate supervisor.

A pre-post measure of absenteeism served as the criterion. The independent variables were casual versus strict enforcement of the attendance control policy and three levels of absence groups (high, medium, and low). It was found that, in comparison to high absence workers in the control group, absenteeism among high absence workers in the experimental group was reduced by a significantly larger extent ($p < 0.05$). The chronically absent workers who were subject to the attendance control policy improved their attendance an average of 7 days per year over the comparison group. The intervention produced no change in the absence rates of the two groups of more regular attenders. However, significant improvements in these two groups were not considered to be as important as improvements in the group of chronically poor attenders. Although the group of chronic absentees was only 25 pct of the sample, they accounted for 56.5 pct of the total days lost.

Mixed Consequences Plans

Plans that include both positive incentives for attendance and negative sanctions for absence have been devised and empirically tested (*21, 32-34*). These mixed consequence plans were generally found to be quite effective at reducing absenteeism. The design of these mixed plans varied considerably. Those who wish to find out the details of each of these plans are referred to the four articles cited. Several leading researchers and practitioners have spoken highly of this type of plan, e.g., Latham and Napier (*35*), Steers and Rhodes (*52*), Baum (*5*), and Adkins (*2*).

Participation in Incentive Plan Design

Two nonmanagement groups are sometimes included in the design of incentive plans to improve attendance: employees and unions. Research suggests that their participation can help to ensure the success of the plan.

Employee Involvement

Latham and Napier (*35*) argue that greater involvement of employees in designing an absentee system may increase their motivation to adopt the system as their own. If the absentee system is seen as their own construction, they will more likely follow its rules. Some of the ways to initiate a program of employee involvement in absenteeism are to (1) provide information about absenteeism rates, costs of absenteeism, and the consequence to the worker, in terms of job security, of high absentee rates; the point is, absenteeism must be perceived as a problem; (2) provide an opportunity for employees to participate in the design of an absenteeism program that will create positive incentives for attendance and punishments for high absenteeism; and (3) provide an opportunity for employees to monitor absenteeism over time and to monitor the effectiveness of their program to reduce absenteeism.

Scheflen, Lawler, and Hackman (*49*) performed a well-designed field experiment on the effects of employee participation in the development of pay incentive plans to increase attendance. Three groups of building maintenance employees developed their own incentive plans to reward high attendance, and identical plans were then imposed by company management in two other work groups. A significant increase in attendance was found during the first 16 weeks following implementation of the plans only in the groups where the plans were participatively developed. Attendance rates were not significantly altered in the groups subjected to the management-imposed plans. A followup evaluation conducted 1 yr after the original plans had been installed revealed that attendance was still higher in the groups that had been allowed to participate in designing their own plan.

Union Involvement

Programs developed by union and management may be another way to deal with absenteeism. As previously mentioned, absenteeism can cause grievances. Therefore, both union and management have a stake in dealing with this issue. Some unions and companies (e.g., United Auto Workers and General Motors) have established joint committees at the national and local levels to seek ways to deal with absenteeism. There are no data available to assess the effectiveness of joint labor-management efforts on absenteeism.

SUMMARY

High absenteeism among underground miners is a threat to miner safety and seriously hampers productivity. Therefore, it is important to understand what factors lead to miner absenteeism and what can be done to control it. There have been two attempts to empirically determine the causes of miner absenteeism, and numerous attempts to determine the causes for absenteeism among employees of other industries. Using the findings from these studies and what is known about coal miners and the mining industry, a conceptual model of the factors that produce absenteeism among coal miners was generated. This model posits that the factors that determine whether underground miners come to work are transportation problems, health status, safety, job involvement, distributive justice, absence control system permissiveness, desire to avoid income loss, attendance norms, personal values, and satisfaction with various aspects of the job. These aspects of job satisfaction include safety, coworkers, equipment, working conditions, opportunities for social activities, advancement opportunities, job content, closeness of supervision, fairness of supervision, and pay.

Several specific strategies for controlling miner absenteeism are identified and discussed. These strategies are designed to decrease absenteeism by (1) improving hiring procedures, (2) removing obstacles that make employees unable to attend work, and (3) increasing miner motivation to attend work.

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EXAMINATION OF THE DESIGN OF BONUS PLANS IN UNDERGROUND MINING

By Paul S. Goodman[1]

ABSTRACT

This paper provides an analysis of the modal bonus plans in underground mining. The basic structure of the plans is presented in terms of 15 different decisions. The modal plan is then subjected to a theoretical analysis, a literature-based analysis, and an empirical analysis. The basic conclusion is that the modal plan in the industry is not strong in eliciting high motivation and performance. Conditions within a mine that are favorable to such a plan and that should elicit success are presented.

INTRODUCTION

The purpose of this paper is to examine the effectiveness of wage incentive plans or bonus plans in underground coal mining. In this paper, the structural features of bonus plans will be examined. That is, any bonus plan represents a series of decisions. The results of these decisions create the specific design or structure of the plan. By analyzing the form of these plans, certain aspects of their effectiveness can be uncovered. These dimensions examine the major decisions a designer must consider in formulating a plan. The paper begins this way to give the reader a picture of a bonus plan that can be referred to while moving through the analysis.

Decision 1: Bonus Calculation Period.—A bonus can be calculated at any time period. A bonus could be paid out daily, weekly, monthly, quarterly, or at some other time period. The selection of the time period is related to the effectiveness of the plan.

Decision 2: Bonus Payout Period.—A bonus can be paid out at the same time it is calculated, weekly, monthly, etc., or, the bonus could be paid out at a time different from the calculation payment. For example, the bonus could be calculated on the weekly basis, but the payout would be on a monthly basis to economize on administration activities.

Decision 3: Form of Payout.—The bonus can be included in a regular payroll check or in a separate check.

Decision 4: Bases of the Plan—Critical Criterion.—Plans can be designed around a number of organizational effectiveness dimensions.

1. Production. Almost all plans reviewed will be based on increases in production
2. Safety. Incentive plans can be based solely on improvements in safety or include improvements in safety and production.
3. Absenteeism. Incentive plans can be based on reduction in absenteeism.
4. Supply costs. Incentive plans can include reduction of supply costs, a base in calculating a bonus.

Decision 5: Designing the Production Bonus Formula.—A critical feature in any plan is designing the formula for calculating production gains. While there are many possible formulas, tons per week, adjusted by the workforce, compared to a standard represents one commonly used production formula.

Decision 6: Selection of the Standard.—All bonus plans are based on comparing actual performance to a standard. So the selection of the standard is very important in the overall functioning of the plan. A standard can be derived from historical data or expected budget estimates.

Decision 7: The Use of Single Versus Multiple Standards.—A unique feature of underground coal mining (versus other types of industries) is that there are frequent variations in physical conditions on production. Since physical conditions are outside the workers control, the question is whether different standards should exist for different conditions.

Decision 8: Determining the Safety Formula.—The safety formula could be based on some combination of frequency and severity of accidents and violations.

Decision 9: Selecting Safety and Violation Standards.—As is true of production formulation, it is necessary to select standards for accident rates and for violations.

Decision 10: Source of Funds for Production and Safety.—If a bonus plan is based on both improvements in production and safety, there is an issue of whether improvement in safety comes from savings only in safety or also from savings in production. Sometimes savings from improvements in safety are not large enough to have a real impact as a safety incentive. Still the organization wants to reward safety.

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Decision 11: Distribution to the Company.—Whatever the basis of the bonus plan (e.g., production, or production and safety) there need to be rules about the share the company receives independent of its employees (managerial and hourly). The company receives a share of the bonus because it is the provider of capital, facilities, and resources.

Decision 12: Distribution of Bonus.—The first option is that management and employees can have a separate bonus plan; the source of funds and the distribution rules would be separate. The second option is that the source of funds for labor and management would be the same but the distribution values for labor and management would differ. The third option is that labor and management draw from the same fund and distribute the bonus on the same basis.

Decision 13: Form of Payment.—The typical form of payment is money. Time off is another option, or some combination of time off and money.

Decision 14: Payoff Schedule.—The bonus can be paid off in a linear fashion or in an accelerated fashion. For example, in the linear fashion, a 5-pct increase may lead to $50 and a 10-pct increase to $100, while in an accelerated schedule a 10-pct increase may lead to a $150 bonus.

Decision 15: Additional Organizational Arrangements.—Some incentive plans introduce a new set of organizational arrangements to increase the likelihood of bonus payouts. Some companies involve employees in the design of the bonus plan. Others use a committee structure to monitor the plan, and to provide employees with an opportunity to present ideas to improve productivity and safety.

MODAL BONUS PLANS IN UNDEGROUND COAL MINING

In this section some empirical data on bonus plans in underground coal mines is presented. The purpose is to illustrate the modal characterization of bonus plans in underground coal mining as well as some of the variation. The objective is to use the modal characterization as a way of talking about bonus plans in the underground coal industry.

The sample consists of bonus plans from 72 underground mines. The plans were initiated during the 1981-84 time period. The mines are located in the eastern U.S. coalfields. Mine size ranges from less than 100 to 500 employees. All 72 plans are from mines with United Mine Workers of America (UMWA) representation. Data on bonus plans from six nonunion mines have also been reviewed. There are no differences in these mines from the 72 UMWA mines; the structure of the bonus plans in union and nonunion mines appears quite similar.

The sample of bonus plans was drawn by convenience. There is no national source of coal bonus plans. The major strategy in obtaining the plans was to use connections in the coal industry established through the Carnegie Mellon Coal Research Program. This research program has sponsorship of 17 major coal producers in the United States. When these organizations joined this project (1981-82) they accounted for about 70 pct of the underground coal produced in the United States. Through these connections and others developed during the course of the project, the descriptions of implemented plans in 72 different mines were obtained.

Are the data representative? There is reason to believe they are. First, the sample of plans that will be reported come from a representative sample of companies under the BCOA-UMWA agreement. Second, the Carnegie-Mellon coal project team talked with a lot of managers and union officials over the last 5-yr period, and the bonus plans learned about through these discussions (but not included in this sample), seem similar in design to those that are reported in this paper. Third, the nonunion bonus plans reviewed by the project team are similar in form to those in the sample of the 72 mines.

The basic position is that if bonus plans from all of the mines with plans were available, the modal characterization would not be different from the sample of 72 mines reported in this paper.

The following 15 tables characterize the 72 plans along most of the decisions that were enumerated previously. For example, plans were coded in terms of whether they paid out weekly or monthly, or whether they paid out with a single check or a separate bonus check. Coding of all of the 15 decisions was not done because of limitations on the descriptions of plans.

Table 1 shows that most of the plans pay out on a monthly basis. The seven observations in the other category refer to six biweekly and one quarterly calculation period schemes. Table 2 shows the period in which the plans paid out a bonus versus the period for calculating a bonus. Most plans paid out on a monthly basis. Table 3 shows that about half of the plans paid out by a separate check, the other half included the bonus payout in the regular check.

Table 1.—Bonus calculation period

Period	*pct*
Monthly	87.5
Other (6 biweekly, 1 quarterly)	9.7
Weekly	2.8
Total	100.0

Table 2.—Bonus payment period

Period	*pct*
Monthly	90.3
Other (6 biweekly, 1 quarterly)	9.7
Total	100.0

Table 3.—Form of payout

	pct
Regular payroll check	51.4
Separate check	48.6
Total	100.0

Table 4 indicates that 61 pct of the plans did not incorporate safety as one of the elements of the bonus. Thirty-nine percent did use improvements in safety performance in calculating a bonus. Table 5 shows that absenteeism is related to the bonus payout scheme. Table 6 indicates that none of the plans used supply costs in determining bonus payments.

Table 4.—Existence of safety bonus

	pct
No	61.1
Yes	38.9
Total	100.0

Table 5.—Absenteeism connected to bonus

	pct
Yes, to production	87.5
No	5.6
Yes, to production and safety	5.6
Yes, other	1.4
Total	100.0

Table 6.—Supply cost included in bonus plan

	pct
Yes	0.0
No	100.0

Table 7 shows that there is a high degree of unanimity about the form of production formula. Tons per week per workforce is compared to a standard tons per week per standard workforce. The appendix to this paper gives an example of specific production formula. Table 8 indicates that production standards were estimated from historical records versus estimated budgets.

Table 7.—Production bonus formula

	pct
Tons per week, adjusted	98.6
Tons	1.4
Total	100.0

Table 8.—Basis for production standard

	pct
Historical	98.6
Expected budget estimate	1.4
Total	100.0

Table 9 shows that all the mines selected single versus multiple standards.

Table 9.—Number of standards

	pct
Single standard	100.0
Multiple standard	0
Total	100.0

Table 10 looks only at the plans that incorporated safety performance in their bonus. For these plans, the majority include both lost-time accidents (LTA's) and violations. The next set of plans with a safety component include only LTA's.

Table 10.—Basis of safety bonus

	pct
Not applicable	61.1
LTA and violation incidences	25.0
Violation incidence and severity	4.2
LTA and violation incidences and severity	2.8
LTA incidence and severity	2.8
LTA incidence and severity and violation severity	1.4
LTA incidence and severity and violation incidence	1.4
LTA incidence	1.4
Total	[1]100.0

LTA Lost time accident.
[1]Does not add to total shown owing to independent rounding.

Table 11 examines the source of the safety bonus. The table indicates that the primary source is savings from fewer accidents and violations.

Table 11.—Source of safety bonus

	pct
Not applicable	62.5
From safety gains	25.0
From both production and safety	11.1
From production gains	1.4
Total	100.0

Table 12 focuses on plans that use production gains to reward safety performance. The table shows that in this case firms are more likely to use production gains for safety bonuses.

Table 12.—Distribution of production gains to safety

	pct
25 pct safety, 75 pct production	1.4
50 pct safety, 50 pct production	13.9
0 pct safety, 100 pct production	75.0
Other	9.7
Total	100.0

Table 13 indicates that money was the form of bonus payment.

Table 14 shows that the majority of the plans paid out in a linear function.

Table 15 presents a summary of the modal characteristics of bonus plans in the coal industry.

Table 13.—Bonus component

	pct
Only monthly payments	98.6
Other	1.4
Total	100.0

Table 14.—Production bonus rate function

	pct
Linear function	97.2
Accelerated function	2.8
Total	100.0

Table 15.—Modal characterization of bonus plan

Bonus calculation period	Monthly.
Bonus payout period	Do.
Form of bonus payout	Separate check or part of payroll check.
Base of bonus:	
Production	Yes.
Safety	Yes.
Absenteeism	Yes.
Supply costs	No.
Production formula	Weekly tons per workforce. Compares to standard tons per standard workforce.
Selection standard	Historical records.
Number of standards	Single.
Bases of safety formula	Accidents and violations.
Selection of standard	Historical records.
Source of funds—safety	Production and safety bonus.
Distribution:	
To company	No data.[1]
To management and employees	Do.[1]
Types of payment	Money.
Payoff schedule	Linear.
Unit of payout	The mine.
Organizational arrangements	No data.[1]

[1]No information in the description of the plans to permit coding.

ANALYSIS OF BONUS PLANS—THEORETICAL

In this section the bonus plans are analyzed in terms of their effectiveness. The tools for this analysis come from motivational theory. That is, the strengths and weaknesses of modal bonus plans will be analyzed utilizing motivational theory. The plan that is characterized in table 15 represents a profile of choices. That structure versus alternative structures has different implications. The theory can provide information about the consequences of that plan.

WHAT DOES EFFECTIVENESS MEAN?

Bonus plans are instituted for a variety of reasons. Some plans are designed to increase retention and to reduce absenteeism and tardiness. Other plans directly focus on increasing productivity or costs. Still other companies introduce various incentives because they are changing the form of the organization, and they want the incentive plan to be congruent with this new managerial philosophy. In this case, the change in management philosophy and culture drives the introduction of the new pay system.

From analysis of the bonus plans and from visits to companies with plans, it seems that improvements in productivity and costs are the primary reasons for initiating bonus plans in underground coal mining. The basic assumption is that the plan will increase motivation, which should in turn lead to improvements in performance and costs. The question posed is to what extent is the bonus plan likely to increase motivation and performance. To the extent that the plan can increase motivation and performance it will be effective.

THEORETICAL ANALYSIS

If the assumption is that a bonus plan will increase motivation and then performance, the analysis initially needs to examine how the structure of properties of the plan affects motivation.

The analysis will focus primarily on the link between the plan and motivation. The reader, of course, can see that increase in motivation might not lead to high performance. A group of employees could be highly motivated, but ability, organizational, or environmental factors may preclude improvements in performance.

What are the conditions that would lead to high motivation? What does it mean to say a bonus plan can lead to high levels of motivation? A condition of high motivation can be characterized in terms of four factors or questions.

1. To what extent do the workers think they are capable of performing at higher levels of performance?
2. To what extent do workers think that improving their performance is linked to rewards?
3. To what extent do workers think that increased performance will lead to punishments?
4. To what extent are the rewards (punishments) from the bonus plan perceived as valuable (harmful) to the workers?

The first question simply asks whether workers perceive (subjective) they can improve their performance. There could be environmental factors (e.g., bad roof) that could preclude workers from being optimistic about increasing performance. The second question simply asks whether improvements in performance are closely tied to bonus payments. More performance leads to more bonus

payments. The third question acknowledges that negative rewards can be attached to any bonus plan. For example, if a crew is opposed to the bonus plan they can exert penalties on workers for participating in the plan. The last question indicates that workers differentially prefer certain rewards to others. Money is not equally valued by all coal miners. Unless the rewards are valued they will not be motivating.

High motivation then means—

Workers believe they can improve performance levels.

High performance is associated with higher rewards.

Rewards are considered valuable.

Only minimal negative rewards are associated with increasing performance.

Table 15 summarizes the structure of the modal bonus plan. How does this plan affect the four questions enumerated previously? In this analysis some structural factors will be more important than others. Also, in many cases the analysis will be on relative impacts of this modal plan on the four questions.

1. *Bonus calculation period.*—The calculation period can affect the motivational levels. Specifically, the shorter the time period the closer the workers will see links between their increased levels of performance and the bonus, and hence, the greater levels of motivation. The shorter time period provides quicker knowledge of bonus payments and avoids negative cumulative effects. This refers to a situation where a miner has difficulty (e.g., bad conditions) meeting the quota early in a period and gives up later in that period thinking he or she is unlikely to meet the quota. The longer the period, the more likely this can happen. Basically this analysis would indicate that weekly calculation periods would be better than monthly, and monthly would be better than quarterly.

2. *Bonus payout periods.*—This dimension is less important because knowing that a bonus was earned is probably more important than knowing it was paid.

3. *Inclusion of safety.*—Inclusion of safety formally in the plan has important motivational consequences. A dominant concern for most miners in this study was that bonus plans could increase accidents. If accidents formally are part of the plan, then it is less likely they will be negative consequences (question 3).

4. *Inclusion of absenteeism.*—Most bonus plans pay out on days worked. So if one works fewer days one gets less bonus payments. There is nothing in this feature that increases motivation to work harder. However, if workers receive the same bonus regardless of attendance, conflicts would result and the plan would not work.

5. *Inclusion of supply costs.*—This feature does not affect the motivational impact of a bonus plan.

6. *Selection of the formula.*—Most of the plans in this study have a fairly simple formula of comparing actual production per workforce to a standard. Simple formulas are important because they facilitate understanding and strengthen the perception about the link between expected performance and bonus payments.

7. *Selection of the standard.*—This is critical because it will affect question 1—to what extent are workers capable of performing at a higher level of performance? If the standard is too high, workers will not respond to question 1 positively and no increased motivation will occur.

8. *Single versus multiple standards.*—A problem with the existing plans is that they only use one standard. The problem is that mining conditions vary. So if workers go through a long period of bad conditions, they will not think they are capable of meeting performance standards and motivational levels will drop off.

9. *The safety formula in most plans is based upon lost-time accident frequency, severity, and violations.*—The important issue is whether workers have control over accident frequency, severity, and violations. To the extent that an inspector, for example, simply writes more violations in one section than another or in one mine versus another, would lower the workers' perceptions that they are capable of reducing violations. The issue is not whether safety indexes should be included, but whether they are controllable. Low perceived control means low motivation.

10. *Selection of safety standards.*—The argument is the same as with production. The standards must be perceived as obtainable by the workers (not simply by management) for motivation to occur.

11. *Source of safety bonus.*—Most plans that paid out on safety used production gains as a source of the safety payout. This is a desirable motivational strategy, because in many of the mines visited it was difficult to generate regular major savings from accident reduction. Therefore, by using some gains from production, the safety reward would be larger and more valuable (question 4).

12. *Types of payment.*—All of the bonus systems used money as a form of payment. However, in our national study of coal miners[2] there is some evidence that money may not be the major motivator and time off may be important. The point is that the plan's effectiveness is based on whether the provided reward is considered valuable.

13. *Payoff schedule.*—The modal bonus plan used a linear versus an accelerated schedule. An accelerated schedule has stronger motivational impacts at higher levels of performance. If workers feel they are capable of performing at higher levels of performance (question 1), then accelerated schedules should strengthen the connection between higher levels of performance and higher levels of motivation (question 2).

14. *Unit of payout.*—All of these plans pay out at the mine level (versus crew). The critical factor then becomes the size of the mine. The larger the mine, the less likely workers will perceive there will be a connection between meeting the standard and receiving a payoff and hence, the lower the motivation.

[2]Goodman, P. S. Feedback on Employee Attitudes in the Coal Industry. Unpublished working paper, 1986; available upon request from P. S. Goodman.

15. *Organizational-technical arrangements.*—While there is nothing in the description of the 72 plans to indicate whether there are complementary organizational arrangements, experience in the coal industry over the last 10 yr indicates there are no organizational arrangements in the modal bonus plans. The problem is there is no feature in the design of the plan to indicate what activities will result in greater productivity. Working harder, coordinating better within and between sections, making suggestions, improving the management of delays, improving the management of supplies, and reducing absenteeism can all increase productivity. However, typically the modal plan does not explicitly focus on any of these critical instrumental behaviors. In addition to focusing on these behaviors there needs to be some mechanism to insure these behaviors get done. That is, there needs to be support activities built into and plan to identify, support, and encourage such behaviors. Such support mechanisms include, but are not limited to, diagnosis of organizational and technical problems prior to introducing the plan, training, formal suggestion systems, and formal review and followup procedures. Some successful bonus systems used in other industries include such support mechanisms as part of the plan.

Table 16 summarizes the relationship between the features of the modal bonus plan and increasing motivation.

A review of the modal plan shows that the following factors detract from the plan's motivation potential.

Monthly calculation time.
Single standard.
Safety formula.
Reliance on pay.
Mine unit of payout.
No organizational arrangements.

The following factors enhance the motivation potential.

Inclusion of safety.
Inclusion of absenteeism.
Weekly tons per workforce formula.
Source of safety bonus.

Table 16.—Modal plan features and motivation

Feature	*Consequence*
1. Monthly calculation time	Reduces motivations (questions 1 and 2).
2. Monthly payout time	No effect.
3. Inclusion of safety	Increases trust and minimizes a negative consequence (accidents) (question 3).
4. Inclusion of absenteeism	Maintains equity.
5. Exclusion of supply costs	No effect.
6. Weekly tons per workforce formula	Simple, facilitates understanding (question 1 and 2).
7. Selection of standard	No direct impacts, depends on level at mine
8. Single versus multiple standard	Single standard will decrease individuals' beliefs that they are capable of meeting expected standards (question 1).
9. Safety formula	To the extent that some of the indicators such as severity or number of violations are outside the control of the worker, the motivation will be decreased (question 1).
10. Selection of safety standard	See feature 7.
11. Source of safety bonus	Inclusion of bonus rewards from production gains increases the amount and hence value of the reward (question 4).
12. Reliance only on pay	Reduces the reward value of the incentive (question 4).
13. Linear pay at schedule	No main effect on motivation, slight preference for accelerated schedule (question 1).
14. Mine unit of payout	In large mines, motivational potential will be reduced (question 2).
15. No organizational arrangements	Reduces motivational and performance potential.

ANALYSIS OF BONUS PLANS—LITERATURE

Another way to analyze the modal incentive plan is to examine the research about incentive plans. Empirical findings in the research literature might help assess the effectiveness of the modal bonus plan in the coal industry. While the literature on incentive plans is not extensive, there are some "stylized facts" that might aid in assessing bonus plans in the coal industry. The type of findings can be divided into two general categories. The first type of findings deal with the inherent characteristics of the bonus plan. The second set of findings deal with organizational factors that contribute to successful bonus plans.

FINDINGS ON INHERENT PLAN CHARACTERISTICS

The following research findings can help assess the effectiveness of the modal bonus plan in the coal industry.

1. *Unit of payout.*—Table 17 provides an analysis by Lawler[3] based on findings in the research literature, about the consequences of different units of payout. The table presents ratings for individual groups and organizational level bonus plans. The mining plan would be characterized as a productivity based bonus at the organizational (mine) level. The basic findings are that organizational plans are average in tying pay to performance, have low negative side effects, are average in encouraging cooperation, and above average in getting accepted. The table also shows that plans based on productivity are stronger than those based on costs or profitability. The mine plans are based on productivity. If one compares across different types of plans, the organizational level plan is less powerful in tying pay to performance as compared with the group or

[3]Lawler, E. E. Pay and Organization Development. Addison Wesley, 1981, 253 pp.

Table 17.—Ratings of various bonus incentive plans[1]

Plan level	Tie pay to performance	Negative effects	Cooperation	Acceptance
Individual:				
Productivity	5	3	1	2
Cost effectiveness	4	2	1	2
Superior's rating	4	2	1	2
Group:				
Productivity	4	1	3	3
Cost effectiveness	3	1	3	3
Superior's rating	3	1	3	3
Organizational:				
Productivity	3	1	3	4
Cost effectiveness	3	1	3	4
Profit	2	NR	NR	NR

NR Not rated.
[1]Low (1) to high (5).

individual plan. This means that the plan will have less motivational qualities.

The most obvious unit of analysis in coal mining is the group or crew and/or section. Coal is produced by a group, not by individuals. In that sense, an incentive at the group or section level appears to be more appropriate. Because crews or sections in coal mines are independent production units, bonuses at the crew level would not lead to competition between groups.

2. *Attractiveness of rewards.*—The research on the attractiveness of rewards has one clear finding: that there are important individual differences in the perceived attractiveness of pay.[4] While it is not clear what are all the predictors of people's preference, there are clear variations in the value people attribute to extra units of money. Given this finding, any program that is based solely on money will have less motivational potential than a program that individualizes rewards; that is, a program that lets people select rewards that are most valuable to them. In addition, there are data from this study that indicate that other factors (time off), in addition to pay, may be important motivators for miners.

3. *Timing of rewards.*—In general, the longer the time period between the performance of desired behavior and the receipt of the reward, the less effective the motivation potential of the bonus plan.[5] The shorter the period reinforces the facts that performance levels can be obtained and that the rewards are closely tied to performance levels. As mentioned earlier, mine bonus plans pay off in a month, which is a relatively long period between initial performance and payoff.

4. *Controllable output.*—Another critical finding is that the workers must perceive they can control the performance behavior that is being rewarded.[6] Factors that affect the perception of control include personality characteristics, physical environment, and equipment reliability. Bonus plans in this study do not reflect the environmental and technological factors that affect coal output that are not indicated in the plan. For example, a long run of bad conditions or difficulties with equipment outside the mining section, would reduce coal production and prevent the attainment of the production standard. When these exogenous factors affect coal production, they weaken the effectiveness of the plan. There is nothing in any of the plans to compensate for these exogenous shocks.

[4]Work cited in footnote 3.
[5]Work cited in footnote 3.
[6]Work cited in footnote 3.

FINDINGS ON FACTORS THAT AFFECT SUCCESSFUL BONUS PLANS

Table 18 is a summary of factors indicating conditions that facilitate the functioning of incentive plans.[7]

Table 18.—Conditions favoring gainsharing plans

Organizational characteristic	*Favorable conditions*
Size	Small unit, usually less than 500 employees.
Age	Old enough so that learning curve is flattened and standards can be set based on performance history.
Financial measures	Simple, with a good history.
Market for output	Good, can absorb additional production.
Production costs	Controllable by employees.
Organizational climate	Open, high level of trust.
Style of management	Participative.
Union status	No union, or one that is favorable to cooperative effort.
Overtime history	Limited to no use of overtime in past.
Seasonal nature of business	Relatively stable across time.
Workfloor interdependence	High to moderate independence.
Capital investment plans	Little investment planned.
Product stability	Few product changes.
Comptroller-chief financial officer.	Trusted, able to explain financial measures.
Communication policy	Open, willing to share financial results.
Plant manager	Trusted, committed to plan, able to articulate goals and ideals of plan.
Management	Technically competent, supportive of participative management style, good communication skills, able to deal with suggestions and new ideas.
Corporate position (if part of large organization.	Favorable to plan.
Workforce	Technically knowledgeable, interested in participation and higher pay, financially knowledgeable or interested.
Plant support services	Maintenance and engineering groups competent, willing to respond to increasing demands.

The table can be interpreted two ways. First, coal mines that have the favorable conditions will have more successful bonus plans. That means smaller mines that are nonunion and have good maintenance groups will have more successful bonus plans. Another way to use the list is to ask whether the organization and technology of coal mining is congruent with introducing bonus plans; that is, there is a lot of similarity in mining coal across all the companies in the study. Is there anything in this process that would facilitate or not facilitate the introduction of a bonus plan?

Table 18 lists a number of favorable conditions unique to coal mining.

Financial measures of productivity are fairly straightforward.

Business is generally not seasonal.

There have not been major capital and technological innovations in the past 6 yr.

Product is stable.

On the other hand, there are a number of conditions that are not favorable to bonus plans. These observations come from an analysis of 25 mines of the 17 largest producers in underground coal in the Carnegie Mellon coal project.

The climate in many mines is not very open.

The style of management is traditional.

[7]Work cited in footnote 3.

Union-management relations are not highly cooperative.

Communication policy is typically not open to share financial information.

Management is typically not highly supportive of participation, asking suggestions, or the bonus plan itself.

Both lists identify factors that facilitate and inhibit the successful utilization of bonus plans in the coal industry.

The basic conclusion that can be drawn from this analysis of the literature is that bonus plans in the coal industry would be more powerful in motivating performance to the extent to which—

The bonus is organized at the crew or section level versus the mine.

The bonus is in a form (money or time off) valued by the worker.

The bonus calculation period is weekly.

The bonus adjusts for uncontrollable events.

The more a given mine can enhance the favorable conditions (table 18), the greater the success of the bonus plan.

ANALYSIS BONUS—MINERS' VIEWS ON BONUS PLANS

In this section, the structure of bonus plans is reviewed by examining miners' views of incentives. Data come from interviews done from a contract with the Bureau of Mines on "Research To Determine the Feasibility of Utilizing Employee Assistance Programs for the Mining Industry."[8] This information was collected at four UMWA mines with incentive plans. Table 19 shows the basic characteristics of the mines.

Table 19.—Mine characteristics

Mine	Size	Location	Technology
1	<400	Virginia	Continuous.
2	<300	West Virginia	Do.
3	<300	do	Do.
4	<300	do	Do.

The mines belong to different major coal companies. While these four are clearly large relative to the average coal mines in the United States, they were similar to other mines in the sample in terms of organizational structure, technology, personnel, and so on. They are representative of large mines in the United States. These four mines were selected because they were the only incentive mines in the initial sample of 25 mines.

The bonus plans in each of the mines match the modal plan (table 15). None of the four companies had paid out more than two bonuses over the last year.

PERCEPTIONS OF BONUS PLANS

Two types of data are examined. The first type of data concern miners' views about design or structure of incentive plans. The second set of data concern the motivational potential of the plan in their respective mine.

Table 20 shows that miners preferred to receive monthly bonus payouts. Unfortunately no questions were asked about the preferred bonus calculation period. Miners were then asked what should be included as the basis of a bonus plan. As table 21 indicates, the majority felt that production, accidents, and absenteeism should be included in the plan. There was less consensus on including supply costs.

Table 20.—Bonus payout period, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Monthly	NA	61	49	63
Biweekly	NA	39	46	28
Other	NA	0	5	10

NA Not available.

Table 21.—Basis for bonus, yes respondents, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Production	100	98	97	83
Accidents	100	86	70	90
Absenteeism	100	85	70	73
Supply costs	72	40	42	59

The formula in all four mines was in the weekly tons per workforce format. Earlier it was argued this was a relatively simple format and should be easily understood. Table 22 shows that most miners report that they have at least some understanding of the formula and operations of the plan. It is interesting to note that less than half the miners have a good or very good understanding of the plan. In mine 4, miners across the board express less understanding of the plan.

Table 22.—Understanding the bonus plan, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Very good	NA	12	9	5
Good	NA	29	39	12
Some	NA	32	30	34
A little	NA	17	9	32
None	NA	10	13	17

NA Not available.

The standard production quota really determines if a bonus will be paid. In table 23 miners were asked whether they thought the standard was too high. In mines 2 and 3, the majority said the standard was about right. In mine 4, the reverse was true.

In table 24 data are presented on what types of individuals should be included in the plan. Respondents seem to prefer a plan that includes UMWA-underground, UMWA-surface, and supervisors. The majority, but to a less degree, feel other production managers, salaried

[8]Goodman, P. S. Research To Determine the Feasibility of Utilizing Employee Assistance Programs for the Mining Industry—Final Report (contract J0100069, Carnegie-Mellon Univ.). BuMines OFR 73-86, 1986, 234 pp.; NTIS PB 86-227089.

safety, engineering, and trainee personnel should be included. There is less consensus on whether mine clerks and other clerical people should be included.

Table 23.—Standard for production, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Too high	NA	23	24	73
About right	NA	77	64	24
Too low	NA	0	12	3

NA Not available.

Table 24.—Who should be included in plan, yes respondents, percent

	Mine 1	Mine 2	Mine 3	Mine 4
UMWA:				
Underground	NA	100	100	100
Surface	NA	87	94	100
Supervisors	NA	98	91	66
Other production managers	NA	64	81	61
Engineers, safety training	NA	73	78	61
Mine clerks	NA	45	62	59

NA Not available.

Miners were also asked whether there should be a separate bonus program for management. Table 25 indicates that most miners felt that there should not be a separate program.

Table 25.—Have separate plan for management, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Yes	100	37	13	50
No	0	63	87	50

Table 26 indicates the type of bonus payment miners would prefer to receive. While there is some variation across the mines, two things can be concluded: (1) Cash is not the only preferred payment, and (2) some combination of cash and time off would be a more preferred payment.

Table 26.—Type of payment, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Cash only	15	34	24	15
Time off only	12	5	6	10
Fringe only	0	0	9	5
Cash and fringe	9	20	12	17
Cash and time off	42	34	33	32
Other	22	7	6	21

In an earlier discussion, it was pointed out that there were no formal mechanisms in the modal bonus plan to direct workers' attention on the critical strategies for increasing productivity. The underlying assumption seemed to be work harder rather than work smarter. There is nothing to assist in coordination, planning, or eliciting new productivity ideas.

To explore the informal functioning of the mines, miners were asked three questions. First, "how often do they talk to their boss about mining activities?" The basic results in table 27 indicate that the majority talk about mining activities at least once a week. The second question was "who was interested in their ideas for improving work?" At least one-half said no one, the next most interested party was the other miners (see table 28).

Table 27.—How frequently boss talks about mining activities, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Once a day	24	31	27	24
Once a week	22	41	40	22
Once a month	5	5	3	5
Several times a year	20	5	3	20
Never asked	29	18	27	29

Table 28.—Who is interested in your suggestions and opinions, percent

	Mine 1	Mine 2	Mine 3	Mine 4
No one	59	56	53	59
Superintendent	5	2	7	5
Mine foreman	5	17	3	5
Other miners	30	12	27	29
Other	1	13	10	2

The third question asked them to generate some productivity improvement suggestions (table 29); at least 50 pct had no suggestions to make. The point is that bonus plans really work if people work harder and smarter. These questions indicate that mechanisms are not in place to let miners work smarter in order to generate new ways to increase productivity at work.

Table 29.—What suggestions could you make to improve productivity at this mine, percent

	Mine 1	Mine 2	Mine 3	Mine 4
No suggestions	NA	76	54	80
Maintenance improvement	NA	10	18	5
Mining techniques-plans	NA	5	11	3
Other	NA	9	17	12

NA Not available.

What can be learned from these findings? In general, many aspects of the modal plan in coal mining is consistent with how miners would like to see the plan designed. However, there are some differences. First, the modal plan relies on cash as an incentive. The data indicate that miners want cash plus other incentives (e.g., time off). Second, there are some differences in who should be included in a plan. Third, and this is not a difference, the understanding of the plan seemed lower than had been predicted given the rather simple nature of the formula. Another point is that whether the standards are appropriate depends on the individual mines. In mine 1, where bonuses have not been paid, respondents feel the standard is too high. The last point is that neither the bonus plans in these mines, nor the organization of the mines, are designed to facilitate productivity-related suggestions that might improve the chances of making a bonus.

A series of questions were asked to determine the motivating potential of the existing plan. Remember that earlier in this paper it was stated that a plan would be motivating to the extent that it led miners to believe—

They were capable of producing more, and

They would receive more if they produced more.

Table 30 indicates whether miners feel they can increase the level of their performance. At least 50 pct felt it was unlikely they could increase their performance over current levels. Less than 20 pct felt it was likely they could increase their performance.

Table 30.—Likelihood of producing more coal, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Not at all	NA	37	17	46
Only a little	NA	34	31	22
Somewhat	NA	13	24	22
Quite likely	NA	13	14	8
Extremely	NA	3	14	2

NA Not available.

Table 31 asks a similar question but focuses on downtime, a major cause of lost production. More than 60 pct felt it is very unlikely they would be able to reduce downtime.

Table 31.—Likelihood of reducing downtime, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Not at all	35	53	31	43
Only a little	38	24	31	27
Somewhat	8	11	31	22
Quite likely	4	12	7	8
Extremely	5	0	0	0

Table 32 asks a different question. Basically it asks if a person did improve his or her performance, would the mine earn a bonus. The data say that a majority of the respondents did not think bonuses would be earned.

Table 32.—Likelihood of receiving an incentive bonus, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Not at all	57	44	57	73
Only a little	30	16	27	20
Somewhat	11	19	13	5
Quite likely	0	16	0	2
Extremely	0	6	3	0

If miners feel they can not improve their performance and they do not think bonuses will be forthcoming, the bonus plan has low motivation potential. One reason miners may be pessimistic about the plan is because it benefits only management and/or it is administered unfairly. Tables 33 and 34 show that miners feel the plan benefits both the miners and the company. In mines 1 and 4, respondents report that the program is administered fairly.

Table 33.—Who benefits from the program, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Primarily—				
The mine	NA	3	7	2
The company	NA	17	22	53
Both	NA	80	71	45

NA Not available.

Table 34.—Administration of plan, percent

	Mine 1	Mine 2	Mine 3	Mine 4
Very fairly	0	5	10	0
Fairly	37	87	67	35
Not fairly	63	8	23	65

The basic finding from these results is that in these four mines the bonus plan does not elicit high motivation potential.

DISCUSSION

A theoretical, literature, and empirical analysis of the structure of bonus plans in underground coal mining has been provided. There are two basic conclusions from the analysis. First, the inherent structure of the bonus plan is not conducive to increase motivation potential and performance.

Plans that—

Pay out at the organizational mine level (versus group),

Pay out only in money (versus other rewards),

Use single standards (versus adjusting for noncontrollable events, e.g., physical conditions),

Are calculated on a monthly basis, and

Provide no organizational arrangements to increase productivity, are not powerful in increasing the motivational or performance potential. Granted there are some positive structural features such as the inclusion of safety and a simple formula, but these do not offset the negative impacts of the features listed. Some mines can have more success with these types of plans than others. These mines would have—

To be small mines with less than 200 employees;

To have a good market that could absorb additional production;

To have good historical production data;

To have relatively stable production conditions;

To have a climate with high degrees of trust;

To have a participative management style;

To have cooperation between union and management;

To have no major capital investment plans;

To have a willingness to share production information;

To have mine superintendents committed to making the bonus plan work; and

To have good support services—maintenance.

This issue is not whether a mine has some of these attributes. All are necessary to make a plan work.

APPENDIX.—PRODUCTION BONUS FORMULAS—MINE X

Bonus = (Number of production shifts worked by individual) × Change in tons per month + change in tons per roster person-day) × (bonus payment),

$$\text{Where Change in tons per month} = \frac{\text{actual tons per month} - \text{standard tons per month}}{\text{standard tons per month}}$$

and Change in tons per roster person days = P − Q/Q,

Where P = actual tons per month/actual roster person-days per month

and Q = standard tons per month/standard roster person-days per month

$$\text{Let } X = \frac{\text{actual tonage per month} - \text{target tonnage per month}}{\text{target tons per month}} \times 100 \text{ pct},$$

$$Y = \frac{\text{actual tons per person-day} - \text{target tons per person-day}}{\text{target tons per person-day}} \times 100 \text{ pct},$$

and Z = regular scheduled production days worked.

Production bonus = (bonus payment) × (X + Y) × (Z).

BASIC GUIDELINES FOR ESTABLISHING AN EMPLOYEE ASSISTANCE PROGRAM

By Nancy D. Campbell[1]

ABSTRACT

This paper discusses the concepts and processes important to the development and implementation of an employee assistance program (EAP). Program planning strategies and marketing tools are reviewed, as are suggestions for training, casefinding, program maintenance, and program evaluation.

INTRODUCTION

From their earliest beginnings in the 1940's and 1950's, employee assistance programs have come to represent one method for dealing with troubled employees whose performance on the job is being affected by outside-of-job factors. The purpose of this paper is to examine the EAP concept and to describe its design, development, implementation, and evaluation. Because the components necessary for the establishment of a successful EAP are similar regardless of the industry involved, such processes will be discussed generically. Those desiring specific information on the feasibility and application of EAP's to the mining industry are referred to an earlier report (*1*).[2] That report established that EAP's are appropriate and valuable when the decision to establish an EAP has been based upon the needs of a specific worksite. This paper will address those processes involved in establishing a viable program. In order to do so, it is important to define the EAP concept and to briefly introduce common issues of use.

THE EAP CONCEPT

An EAP is a structured approach for assisting employees with those off-the-job problems that can affect job performance. While EAP's were initially designed to identify and help those employees with alcohol problems, the EAP's of today generally take a much broader perspective. In addition to alcohol and drug abuse, a myriad of other problems—marital-family, physical, financial, legal, and vocational—can negatively influence job performance. Most often a combination of such problems are present. Thus, the role of the EAP system has expanded in the past two or three decades and reflects the growing concern for achieving and maintaining an emotionally healthy workforce.

While EAP's come in a variety of forms, they typically involve self-referral or referral by a supervisor or union representative for an off-the-job problem. The EAP coordinator evaluates the problem and refers the individual and/or family to the appropriate treatment agent in the community. The diagnostic sessions are usually covered by the organization's insurance program, while ongoing treatment services may or may not be so covered. Most EAP's operate off site, utilizing professionals on contract, while some may elect to develop in-house programs utilizing professionals who are on staff. Such design decisions will be discussed more thoroughly in the sections to come.

In general, the overall goal of an EAP is to restore the employee to normal work behavior and productivity and/or prevent work performance problems due to personal concerns. The power of this approach rests both with early identification and with the motivating elements inherent to employment. People want to keep their jobs, and the possibility of losing one's employment is a strong motivational force in getting the troubled employee to seek help.

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[2]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

ESTABLISHING AN EAP

The purpose of this section is to describe in more detail the specific developments needed to establish a viable EAP system. As with any proposed program or service, careful planning and thorough attention to the implementation of that plan are essential to program success. At a minimum, such a plan should include (1) identification of need, (2) joint labor-management planning, (3) program design, (4) orientation and training of management, supervisors, and employees, (5) program maintenance, and (6) program evaluation. Each component will be discussed in more detail in the sections to come.

NEED IDENTIFICATION

Prior to establishing an EAP, an organization must recognize that it has a need for such services and demonstrate a commitment to identifying strategies for addressing this need. The initial interest in establishing a program may be generated by a specific segment of the workforce, but ultimately there can be no program without the full cooperation and support of key personnel at all levels. Any number of events might precipitate serious discussions—an increase in accidents, absenteeism, an attempted suicide, labor-management contract negotiations, an emerging awareness of health and wellness issues by top-level management.

In general, management-initiated discussions represent the most common starting point and must clarify early on who has the authority to make programming decisions. In those companies where authority is decentralized, the manager at each site can set policy without obtaining corporate approval. In other more centralized organizations, home-office approval is required before any change in existing policy can be initiated (*2*).

Once determination of authority has been examined, clarification of the scope of the problem can be pursued. Involvement of both labor and management becomes crucial in assessing the prevalence and incidence of factors potentially affecting job performance and in establishing a rationale for pursuing an EAP. Frequently, an outside consultant knowledgeable about EAP's is brought in to facilitate the process, and it is usually wise to initially stage separate discussions with labor and management to encourage freedom of expression. If both sides unilaterally decide that an EAP is justified, then the stage is set for a joint labor-management dialogue.

LABOR-MANAGEMENT DIALOGUE

The purposes of the labor-management dialogue are (1) to encourage cooperation and support for the program, (2) to jointly assess those elements within the work setting likely to impact successful development of a program, and (3) to establish a joint labor-management planning committee responsible for the creation of policy and the setting of goals, the overseeing of program development and implementation, and the identification of marketing strategies (*3*). Each of these activities will be discussed in the following sections.

The Involvement of Key Individuals

The support of key individuals at all levels of labor and management is essential, as is the identification of those gatekeepers who are unlikely to support the efforts. Because an EAP must operate within the existing network of organizational relationship, it is imperative to know the lay of the land, the vested interests, the social politics, and the formal and informal lines of authority and power. The involvement of both formal and informal leaders works to establish a system of endorsement and trust that is invaluable, and that will more likely lead to substantial future labor-management referrals. It is also suggested that a representative of the existing medical staff be included at the inception. This is to ensure that the EAP will not be regarded as a threat to current medical services and will be utilized as an option by medical practitioners at the worksites. Personnel and training departments should also be included.

These key individuals form an ad hoc committee responsible for selecting a permanent EAP planning committee and for identifying its goals and objectives. Ideally, planning committee members will be chosen with these goals in mind and will be made clearly aware of the committee's purposes before they are selected.

Planning Committee

The major purposes of a labor-management planning committee are to establish EAP goals and objectives, develop policies, select the appropriate EAP design, and identify strategies for program promotion, training, and casefinding. Members should have sufficient formal and informal power and authority to ensure that committee decisions will be acceptable to the workforce at large. Subsequent to program implementation, the committee is to operate in an advisory capacity only, leaving program details to those so hired, and it must continually evaluate both the effectiveness and the necessity of its advisory function.

EAP Goals

While companies initially pursue an EAP with some rationale in mind, it is important that these become formalized goals prior to program implementation. Such goal setting clarifies both the scope of the proposed program as well as its limitations, and establishes guidelines for the development of policies and procedures. Several goals have been identified that are characteristic of EAP's in the mining industry (*1*). These goals include reducing problematic on-the-job behaviors such as absenteeism, accidents, etc., and increasing worker productivity, providing an alternative method for handling disciplinary problems linked to employee's personal problems, and increasing employee health and well-being. The task at hand is for the EAP goals to be clearly identifiable and acceptable to all, and to be truly representative of the concerns of the organization.

Policies and Procedures

Once the EAP goals have been established, they need to be incorporated into a written set of policies and procedures that govern the activities of the program. In preparation, present documents need to be examined to determine (1) the present policy (or lack of one) on alcohol and drugs, (2) the procedures currently used, both formally and informally, to handle troubled employees, (3) the present employee benefits program, and (4) the current personnel practices and union contract.

The operation of an EAP affects all aspects of the company's human resources system, including its policies on discipline, absenteeism, alcoholism, and drug abuse. Thus, a consistent set of policies needs to be generated that is acceptable to labor and management. Because medical benefits are likewise implicated, such policies also need to be reviewed to reflect the activities of the EAP. Any policies drafted must of course address the issue of confidentiality and must clearly state the scope and limitations of such confidentiality. In addition, policy distinctions should be made between self-referrals and supervisory referrals and the differing confidentiality parameters of each. Generally, self-referrals remain entirely confidential, unless the employee desires otherwise and signs a release form. Supervisory referrals generally require the employee to sign a release of general information to the supervisor, although this may be waived by the supervisor. Nevertheless, the general guidelines, and their exceptions, should be clearly delineated.

Program Design

The development of program procedures generally overlaps with program design, as each influences the other. Program design usually requires decisions on (1) the population to be included, (2) the types of referrals to be utilized, and (3) the provider of the service.

An EAP can be designed for employees only or can include family members as well. While employee-only programs are less expensive, family problems are major influencers of job performance. Once again, the demographics of the particular worksite should provide the data necessary for such a decision. However, most EAP's in the mining industry include both employees and immediate family (*1*).

The next decision concerns the types of referrals to be utilized in the system. Here referral defines who can initiate help-seeking via the EAP, and there are three possibilities: (1) management referrals, where the company requires that the employee seek help; (2) union referrals, where labor suggests that the employee seek help; and (3) self-referrals, where either the employee, a family member, or a coworker voluntarily initiates the EAP contact. Most generally, all three referral types are encouraged, and a high number of self-referrals is usually the hallmark of a successful program. Also, the broader the network of potential referral sources, the more effective the program is likely to be.

Once the population to be served has been identified and the potential referral sources delineated, the organization must decide who will provide the services, the organization itself or an outside vendor. The services to be provided usually include initial problem diagnosis and assessment, referral, treatment, followup, and training. Companies will differ in the degree to which they wish to become involved in actually providing the program services.

While some larger companies are willing to incur the higher costs of establishing an in-house EAP, most programs prefer to contract with outside vendors who provide the services noted. Such vendors may be localized services or those provided on a national basis, and often the package is available on a cost per employee, per year basis. Although in-house programs can be more finely tailored to the needs of the specific worksite, these programs often report that employees use them less because of fears that confidentiality cannot be assured in-house. This is not usually an issue with programs provided off site by contracted vendors.

Marketing Strategies

The expertise of the joint labor-management planning committee is invaluable in identifying marketing strategies geared toward the various constituencies in the workplace. Supervisory training, employee training, and the training of other special groups (labor relations, personnel, safety, medical department) are strategies that both introduce the program concept and clarify its appropriate usage. Likewise, various types of printed media are obvious ways to foster program awareness and acceptance and include brochures, letters to employees, letters to the families, posters, and articles in the company and/or employee or union newsletters. Such materials should be distributed on more than one occasion.

These formal communication methods must also be reinforced by more personal communication methods, such as meeting with different employee work groups and work shifts, to allow a more informal exchange of program information. Such meetings may include relevant films or videotapes. Special organizational events can also be utilized for program promotion—luncheons, awards banquets, union get-togethers, etc.

EAP marketing strategies can become as creative as is allowable. However, without sufficient attention-getting maneuvers that are sustained over time, a potentially successful EAP can wither from neglect.

ORIENTATION AND TRAINING

Once the EAP concept has been accepted, the program designed, and the necessary policies and procedures developed, the stage is set for the orientation and training of employees, supervisors, management staff, and union representatives. This is the most effective method for educating all levels of the workplace on the EAP, its policies and procedures, referral process, and confidentiality. Such awareness training can be utilized to instruct employees on various aspects of mental health and mental health difficulties, how to spot these difficulties, and the importance of seeking help for these problems before they escalate. Resistances to help-seeking can also be addressed.

The orientation of employees also serves an important marketing function and has been shown to increase both the number of self-referrals and the number of coworker referrals (*3*). Because more than half of the referrals to an EAP generally fall into these two categories, the impact of orientation training cannot be overestimated. It is also important that training be conducted periodically. The more exposure to the program, the more likely that self-referrals will continue.

Given that identification of deteriorating job performance usually falls to the first-line supervisors, training is important in providing them with the tools necessary to (1) identify job performance problems, (2) confront the problem employee, (3) refer to the program, and (4) organize employee followup. Once again, this training should be conducted periodically in conjunction with the company's personnel or human resources department.

KEY PROGRAM COMPONENTS

This section will delineate in more detail three components crucial to the success of an EAP: (1) the EAP coordinator, (2) the supervisor, and (3) the voluntary referral. Although these elements have been introduced earlier, they are significant enough to warrant further discussion.

EAP COORDINATOR

The EAP coordinator is responsible for assessing all referrals coming into the program and for subsequently linking these individuals and/or families with the appropriate treatment providers in the community. The EAP coordinator maintains contact with the treatment providers and establishes an appropriate system of client followup. This followup communication includes regular personal contact with the client as well as periodic written or oral reports to the company about the client's general progress if the EAP referral was company-supervisory initiated because of deteriorating job performance.

In cases where an employee has had inpatient psychiatric or chemical dependency treatment, the EAP coordinator's job becomes one of easing the employee back into the work setting with as little trauma as possible. One effective way of doing this is to initiate a return-to-work conference that brings together the treatment counselor, if possible, the employee, and the employee's supervisor to discuss issues surrounding the employee's resumption of work responsibilities (*4*). The employee can be updated on events at work, job performance issues existing prior to treatment can be addressed, and any other employee or supervisor concerns can be identified.

The EAP coordinator's role obviously requires a thorough knowledge of available community resources and full understanding of the company's insurance policies and benefits. In addition, the coordinator is usually involved in marketing activities and training, and must keep some basic statistics on EAP utilization. However, as discussed previously, only in the case of company-supervisor referrals for deteriorating job performance does the coordinator discuss a particular case with anyone other than the treatment provider. To ensure the utmost confidentiality, the coordinator should be housed in a neutral location outside of the company setting.

THE SUPERVISOR

Supervisors are in an ideal position to do something about employees whose job performance may be deteriorating because of off-the-job problems (*5*). Given their responsibilities for monitoring and evaluating job performance, they are ususally the first to see declining work habits. In addition, the supervisor has the tools available to create the crisis so often needed to motivate a troubled employee to seek help—the disciplinary procedures of the organization. Thus, the supervisor becomes a key mechanism for communicating the company's plan to the employee and for motivating the employee to participate in it.

To fulfill such a vital role, supervisors need to be adequately trained in the policies and procedures of the EAP, in using criteria to identify, evaluate, and document job performance, and in communication skills for effectively encouraging troubled employees to seek assistance. Training should also emphasize that the supervisor is not expected to diagnose employee personal problems nor to refrain from using the usual disciplinary actions as needed. The EAP referral is an additional option for the supervisor and one that may be employed in conjunction with the necessary discipline.

The process of supervisory intervention entails some key behaviors: (1) problem identification, (2) employee confrontation, (3) referral for assessment, and (4) treatment and followup.

Problem Identification

Given the primary role of supervisors to plan, organize, direct, and control workers in the service of production goals, they become empowered with both the opportunity and the responsibility to observe and act on employee behaviors that are in violation of company policy. Because appropriate worker behavior is defined by the job performance criteria established by the organization, deviations from these norms are described in terms of these criteria—absenteeism, tardiness, poor quality work, etc. The supervisor is not responsible for diagnosing a worker's personal problems in terms of mental health concepts. That is the role of the EAP coordinator. The supervisor's role is to identify deviations from acceptable job performance.

Once such an identification has been made, the supervisor has two alternatives. Firstly, he or she may decide to keep an eye on the situation and see if it resolves itself. Secondly, he or she may confront the employee, wait to see what happens, reconfront if the poor performance continues, and refer the employee to the EAP. Two methods have been found helpful in identifying the point at which an employee's performance indicates a problem (*5*). One method focuses on changes in previous patterns of any employee's work behavior. Significant deviations from the normal established pattern for that employee indicate that a problem is likely developing. Another method compares

an individual's work behavior with the norms for the worksite as a whole. Significant deviations from the group norms suggest that something is askew.

Both of these methods rely on the documentation of a performance decline as the evidence that there is a job performance problem. Without such documentation there is no verifiable proof that something is amiss requiring the services of the EAP.

Employee Confrontation

Once the deteriorating job performance has been identified and documented, the supervisor may decide to confront the employee with the documented deficiencies. A request is made for the employee's return to an acceptable level of job performance, with or without the involvement of the EAP. When confronting an employee, the supervisor must communicate both a sincere desire to help and the certainty of disciplinary action if poor job performance continues. It is also important to confront the employee before it is too late. A verbal warning should be issued as a job performance issue becomes apparent.

Employee Referral

Referral occurs when the problem cannot be resolved within the supervisory framework and a confrontation has not been effective in mobilizing change. Within the usual disciplinary framework, the EAP provides the supervisor with an alternative to the shape-up or ship-out approach (*5*), provided the supervisor is aware of the option. At this point, the employee either accepts the referral to the EAP, or rejects the referral. In either case, the employee will experience the typical disciplinary action if job performance does not return to acceptable levels within a reasonable amount of time.

Employee Treatment

The supervisor is least involved in this stage of the EAP process. However, it is important that the supervisor support and protect the employee's position once the employee agrees to seek help and that the supervisor supports the return of the worker to his or her position should an absence be required. In come cases, the supervisor may directly relate to the EAP personnel regarding an employee, within the confines of confidentiality, and may take a more active role is an employee's transition back into the workforce.

THE VOLUNTARY REFERRAL

While much emphasis is placed on the role of supervisory referrals in the success of an EAP, the actuality is that most EAP referrals are either self or family referrals or referrals by coworkers. This fact makes voluntary referrals the mainstay of most successful EAP's and suggests that activities found to be helpful in encouraging such referrals are well worth the effort. In addition, a self-referral usually occurs before the problem has begun to affect work performance and thus represents the ideal EAP situation.

Employee training is a most effective marketing tool and has already been discussed, as have other publicity methods. These methods must repeatedly emphasize the confidentiality of self-referrals, as must the EAP coordinator's behavior when receiving them. Self-referrals are also more likely to occur when the diagnostic sessions are free of charge. This sets up an atmosphere of perceived company involvement and concern that is more conducive to employees' taking responsibility for addressing personal issues.

Employee trust emerges over time as the program proves itself to be worthy. Satisfied consumers are the very best advertisement, and a few test cases are required before a general acceptance can be expected. Positive employee experience with the program, coupled with ongoing orientation, training, and publicity will heighten awareness, generate referrals, and create a firm EAP foundation.

PROGRAM MAINTENANCE

Program maintenance requires developing a flexible plan that will sustain a level of meaningful EAP activity. Four strategies for maintaining high visibility include (1) ongoing marketing efforts, as have been discussed, (2) personnel updates and briefings, (3) program monitoring, and (4) community resource linkages (*6*). These activities are usually conducted by the EAP coordinator.

PERSONNEL UPDATES AND BRIEFINGS

Updates and briefings keep all supervisors, union stewards, and other involved personnel informed about the current state of the EAP. This keeps the important players aware and serves to generate positive feelings about the program. Such interorganization meetings also provide a forum for discussions and suggestions about the EAP services, and for updates on EAP training events, meetings, and activities.

PROGRAM MONITORING

Routine monitoring of the EAP caseload and referral flow can provide early cues as to the evolving nature of the program. This monitoring process includes (1) collecting referral contact forms and analyzing these data, (2) documenting both verbal and written feedback on program services, (3) studying referral networks within the organization to discern patterns of use, and (4) comparing referral methods to determine the more effective procedures.

COMMUNITY RESOURCE LINKAGES

Effective program maintenance depends upon quality working arrangements with a wide variety of community resources. These working alliances are evaluated in a number of ways: (1) by personally visiting those agencies in the area that might provide needed services, (2) by

screening particular agencies according to criteria deemed important for effective and efficient employee usage, and (3) by monitoring employee satisfaction with the community resource services provided (*6*). Ultimately, employee trust in the program is fostered by employee satisfaction with the program, and program monitoring makes possible program evaluation.

PROGRAM EVALUATION

Goodman (*1*) proposes an evaluation model for assessing EAP effectiveness in the mining industry that utilizes three categories of variables: inputs, processes, and outcomes. *Inputs* refer to the employees who are being treated by the EAP, and evaluation concerns the level of awareness and usage of the program by the employees. Obviously, a program can be considered effective if the individuals who need the services are aware of and utilize the services.

Processes involve those services rendered by the EAP and include diagnosis, referral, followup, and training. Effectiveness ratings would examine (1) the existence and comprehensiveness of EAP policies and procedures, (2) the thoroughness of policy distribution, (3) the level of employee knowledge of the program, (4) the system for communicating with and educating the employees and supervisors about the program and how to use it, and (5) the accuracy of referrals made and existence of a followup process.

Outcomes are those problematic job behaviors that the EAP is designed to alter or remediate by resolving off-the-job difficulties. Such behaviors include accidents, absenteeism, low productivity, grievances, etc. A comparison of rate of frequency of these behaviors pre- and post-EAP implementation could provide an estimate of program effectiveness in countering problem behaviors.

Although often an afterthought, program evaluation is essential in allowing an EAP to grow, change, and modify its processes to meet the requirements of the worksite. As such, the purpose of evaluation is not only program justification. Without it, even the finest of programs can become unresponsive to the changing needs of the work environ. Only formal, systematic evaluation addresses a program's need for feedback.

CONCLUSIONS

The mining industry, as well as others, is reaching out to its troubled employees and is formulating new ways to restore them to a healthly, productive state. The national concern for optimal mental and physical health has found its way into the workplace, and the employee assistance concept is one programmatic answer.

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EMPLOYEE ASSISTANCE PROGRAMS, BENEFITS OF SERVICES, AND ACTIVITIES OF THE MINING INDUSTRY SUBSTANCE ABUSE COMMITTEE

By Frank C. Fantauzzo[1] and Suzanne Smith[2]

ABSTRACT

This paper was prepared to explain a general employee assistance program (EAP), its services, and the benefits of an established EAP at the worksites. In addition, this paper discusses the activities of the Mining Industry Substance Abuse Committee.

INTRODUCTION

America's workforce is the heart of the nation's economy; the health of its members is a matter of national priority. Statistics show that the most common cause of job difficulties is the excessive use of alcohol or other drugs. Statistics also show that up to 75 pct of these troubled employees can be returned to productive careers with little expense and great benefits to their industries.[3]

Only 531 of the 1.5 million private corporations in the United States have alcohol treatment programs and far fewer have drug abuse programs. It is time that the myths and prejudices surrounding alcohol and drug abuse are dispelled and help is offered. Corporations and labor unions are finding that programs for the treatment of these diseases are of benefit of both employees and industry in terms of health and job security for the one; increased productivity and decreased costs in sick pay and absenteeism for the other.

Unfortunately, three-fourths of the Nation's 90.5 million workers are employed in establishments of fewer than 500 employees; where it is unlikely that either management or the unions will take the initiative in developing programs.

Alcohol alone affects the health and productivity of almost 8 pct of any workforce, and thus nearly 5.1 million employees in small business. These workers present an opportunity and a challenge. Alcoholism and alcohol abuse cost the nation nearly $116 billion annually. Seventy billion dollars is attributed to lost production. Health and medical expenditures, as a consequence of alcohol-related health problems, are estimated to be $12.7 billion.

The cost of substance abuse to industry has been estimated by the National Institute on Drug Abuse (NIDA) to be in excess of $4 billion per year. In addition to its economic impact, substance abuse has serious personal and social consequences. Human suffering resulting from alcohol and drug abuse is incalculable.

The need for industrial concern and active involvement is underscored by the magnitude of these consequences.

It is believed that the mining industry experiences, though to an unknown quantity, the same exposure to alcohol, drug abuse, and other employee problems as other industries. However, the existence of these problems poses a particular mine safety hazard because of the unique conditions found in mining.

Mining is known as an industry having many safety and health hazards, and employees must have full control of their faculties and be capable of giving full attention to the tasks at hand.

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DESIGN CHARACTERISTICS OF INDUSTRIAL EAP'S

An EAP is a cost-effective,[4] confidential, early intervention system designed to help employees with problems that interfere with their ability to function on the job. An EAP serves to identify and assist employees impaired by alcoholism, drug abuse, mental illness, and other human problems. An EAP can be very effective because it leads to earlier problem identification.

Studies have shown that procrastination in seeking assistance can reduce potential recovery rates from 80 pct down to 15 pct or lower.[5] Because the EAP approach strives to be nonthreatening to the employee, identification takes place earlier.

Unions have long been advocates of programs designed to rehabilitate rather than terminate employees, and initial implementation procedures call for labor involvement at the very beginning. The employer provides assurance to the employee that the program's primary objective is to help and not to harm him or her. EAP programs can be developed in a unionized operation and also in a nonunion operation with the same procedures and principles. EAP's come in many forms, the purpose of this section is to identify several, and initially, programs may be formal or informal.

THE INVISIBLE PROGRAM

One major factor is the assumption by top management or labor that problem drinking and substance abuse, since they are frequently not visible or not reported, do not exist within the company or union. Middle and lower management or union personnel may conceal cases, since they believe that the recognition of such problems will reflect badly on their work records.

The result is that top officials rarely learn of a case of problem drinking or drug abuse until the employee's work performance has deteriorated sufficiently that he or she must be terminated. Management and union heads then are deluded by the impression that these infrequent, severe cases are the only ones that need to be dealt with. Another common assumption is that drug problems are limited to younger age groups and that only a very small percentage of employees are susceptible to either alcohol or drugs, which precludes a realistic assessment of the extent of the problem.

Many companies and unions do not have formal policies or procedures for dealing with behavioral problems but operate under an informal, covert, word of mouth system—usually one of concealment.

The company will pay economic premiums (in fringe benefits, job security, and promotion opportunities) to alcoholics and their supervisors for successful concealment of the problem from higher levels of management. When the alcoholism has reached the point where it cannot be concealed from the attention of top management, the alcoholic's services will be terminated. This means that industry often retains an unproductive employee for an average of 12 to 17 yr before terminating him or her, will pay out large sums in health insurance claims for problems secondary to the causal condition, will tolerate increased accidents, but will not help the employee with his or her basic problems.

The following 29 yr work record (starting in 1957) of a troubled employee (table 1) clearly illustrates how such an unwritten policy works, and further shows how much earlier the problem could have been dealt with by a policy of constructive confrontation.

In 1985, for the first time, successive steps of corrective discipline of any type were taken with full and proper communication between company and union. Offers of confidential help made were at each step. After three steps of a four-step procedure, employee asked help in admission to a substance abuse treatment center.

This work record shows that not only were early warning signs ignored, but that the company's unwritten policy actually distorted standard personnel practices. It is also noted in table 1 where standard company policies were either inconsistent or not followed through. This example also demonstrates how in the absence of an agreed policy, the company and the unions can work against each other to their mutual disadvantage and the employee's detriment.

Although the concept of constructive confrontation is simple, there are many problems involved in the implementation of such a program.

These stem mainly from the fact that alcoholism and drug abuse have an aura of disgrace and shame. As a consequence, many organizations labor under an unrecognized, but active system of nonrecognition and concealment.

WHAT IS A FORMAL EAP?

A formal EAP has a system of policies, procedures, and attitudes, which takes an early positive intervention and is based on unsatisfactory job performance. A formal EAP offers confidential, approachable help, and is viewed as a cost-effective program. This will help provide ways for correct referral, treatment, and followup to assure maximum rehabilitation for the troubled employee.

In addition, these programs, whether management or union inspired, or staffed by outside consultants, provide several types of services.

1. They create an awareness of the problem. The first step in creating a program is the recognition that an alcohol and drug abuse problem exists and it must be dealt with. Because of the stigma attached to problem drinking and drug abuse, and the unwillingness on the part of those

[4]Bureau of National Affairs (Washington, DC). Speical Report: Alcohol & Drugs in the Workplace: Costs, Controls, and Controversies, 1986, 122 pp.
[5]National Institute of Alcohol Abuse and Alcoholism. Study Utilization of EAP's. 1985, pp. 15-16.

Table 1.—Work record of a troubled miner operator

(Male, age 47 at time admitted for alcoholism treatment (Oct. 9, 1986); 29-yr service (employed Apr. 15, 1957); primary health problem: alcoholism and drug dependency)

Dates	Events
Apr. 1957–69	Personnel records and fringe benefits claims showed nothing unsatisfactory or unusual.
1970	Jaw fracture (off the job); 3 episodes of flu, colds—9 days off; $168 insurance claims.
1971	Garnishment. Back pain; 2 episodes of flu, colds—5 days off; late for work 4 times, excuses: car trouble, sick child, car trouble, family trouble.
1972	Acute bronchitis—10 days off; late for work 6 times, verbal and written warnings given; 2 failures to report off, written warning, Nov. 1972, that 1-day suspension would occur on next offense; $56 insurance claim.
1973	Failed to report off in January, verbal warning;[1] sore throat, nausea, upset stomach, nervousness, colds, absences totaled 18 days in 1- to 3-day periods; 4 tardies with excuses of car trouble, family sickness, etc.
1974	Sickness absences, 19 days; tardy 3 times; failed to report off twice; 3-day suspension given, union protested too severe, reduced to 1 day.
1975	Off the job accidents; $376 insurance claims, gastritis, nervousness, colds, trips to nurses aid station for medication.
1976	Written warning about absenteeism and laxity in reporting off,[1] 3 months of fairly good record then absenteeism pattern resumed; garnishment (2).
1977	Sleeping on the job, written warning; off during long strike.
1978	Off the job—auto accident, $235 insurance claims, garnishment; headache, cold, flu, stomach trouble, car trouble, nervous conditions, 29 days lost time.
1979	Discovered he could get elixir terpin hydrate at doctor's office by pleading throat infection: record of 42 such requests during the next 6 yr; began taking vacation time in small chunks, often tied to beginning or end of sickness or personal absence.
1980	Discovered that by getting a doctor's slip at start of illness could avoid most warnings and suspensions; found an aged physician who signed easily and examined little; uncle died—said he had to help settle estate, 8 days absent.
1981	Garnishments (3); sleeping on the job; insubordination; chronic absenteeism—dismissed; union protested; reinstated—"last-chance" agreement signed by company and union.
1982	Death in family, 7 days absent; car accident, $49 insurance claims; tardy twice; acute gastritis; 24 days absent, $633 insurance claims.
1983	Garnishments; gastritis; reported for work intoxicated, verbal warning.[1]
1984	Sickness-absences, 24 days.
1985	Company and union agreed to general policy on alcoholism and related problems. Steps taken to begin developing motivation and assistance measures. Acute gastritis; $802 insurance claims; garnishments, sleeping on the job, usual absenteeism patterns, 1 verbal warning; off-the-job accident; $32 insurance claims.
1986	Memorandum that machine downtime had been excessive during the past 2 yr;[1] summary of absenteeism and disciplinary actions in 1985 made; sleeping on the job; reporting for work intoxicated.

[1]Standard company policies either inconsistent or not followed through.

in authority to acknowledge such difficulties in their companies, recognition is by no means an easy step.

2. They educate. These programs educate both labor and management on the scope and nature of the problem. They learn that alcohol and drug abuse are treatable conditions and that the workplace is a good place for implementing a successful program. The programs illustrate the effectiveness of constructive confrontation and the tangible advantages to both the employee and the company—the former through improved health and continued employment, the latter through increased productivity and profits.

3. They necessitate organization. These programs require the company and the union to take organized action. The normal disciplinary and reporting systems of both are restructured to accommodate the policy of constructive confrontation—to establish formal steps for dealing with those who need help. Supervisors, shop stewards, management, and employees are alerted to the fact that these procedures are in effect and are informed of their respective roles.

4. They refer. A working relationship is established between local businesses and community resources. The program provides a linkage for referral, treatment, and rehabilitation.

5. They follow up. Each employee's record in the program is evaluated. The program should determine if treatment and rehabilitation were effective and ensure that maximum benefit is achieved for both the company and the employee.

FORMAL EMPLOYEE ASSITANCE PROGRAM COMPONENTS—POLICY AND PROCEDURES

The policy agreement should be one signed by the chief executive and chief union representative where appropriate. The function of their agreement will be to provide a clear statement of the purpose, incentives, and benefits of the program. The agreement will provide a basic frame of reference that is essential, both in development of procedures to be followed on implementing the policy, and as a guide for uniform administration of all elements of the program. It encourages the individual's voluntary utilization of the program by the assurance of confidentiality, job security, adequate insurance coverage, and acceptance of the disease concept of alcoholism, drug abuse, and mental disorders.

The policy statement and procedure will serve as a valuable training tool for all union and management personnel involved in implementing the policy itself.

Confidentiality

The written rules should be established specifying how records are to be maintained; for what length of time; who will have access to them; which information will be released to whom, and under what conditions; and what use, if any, can be made of records for purposes of research, evaluation, and reports. Employee records maintained by an EAP should never become part of an employee's personnel file. The record-keeping files should be designed to protect the identity of the employee, while facilitating case management and followup and providing ready access for statistical information.

Team Work

Some formal EAP's, mainly in large corporations, employ an in-house counselor, or subcontract to local mental health hospital or local counseling clinic. The responsibility for the EAP counseling it to coordinate the EAP program.

The counselor should show concern and interest for the employee, yet, motivate this person to explore the possibilities of treatment. The responsibility of the EAP conselor is to identify an employee's problem. The professional mental health counselor or medical professional is able to diagnose alcoholism and substance addition.

The EAP counselor should—

Have current listings of agencies and services for treatment;

Insure confidentiality;

Work with an EAP worksite joint-committee of management and labor; and

Arrange visits to treatment agencies for the joint committee for knowledge and evaluation.

Joint (Management and Labor) Committee

A joint committee of the workforce organization should be formed of equal numbers representing management, union employees (if the employees are organized), and nonunion employees. This in-house committee follows an outline of agreed-upon procedures.

The joint committee will secure effective cooperation of all agencies within the community and evaluate which provide treatment services.

The joint committee will develop a record-keeping system that assures confidentiality to employees.

The joint-committee will approve any training program for company supervisors, union representatives, and EAP counselors. All training should take place with company and union representation attending at the same time.

The joint committee will assess the program on a regular basis and make changes where appropriate.

Awareness Programs

All employees and their families should be informed about the organization's EAP and the services it offers. Educational techniques should be employed to provide update information on the EAP and its benefits. The information should be mailed to the employee's home.

A training program should be developed for all levels of supervisors, labor representatives, and joint committee members, which will assure implementation of the program.

Such a program could include—

An explanatory message from a responsible individual.

A short film that is designed to acquaint the supervisors and labor representatives with a better understanding of illnesses covered under the EAP services and methods of referrals to professional counseling or diagnostic services.

A clear definition of the responsibilities of the supervisors and labor representatives with respect to the procedures with which they are charged in implementation of the program.

Use of charts or visual aids in instruction on procedures to be followed including:

1. Proper documentation and evaluation of unsatisfactory work, work performance or behavior, and of all corrective action taken.
2. Clues and record reviews to use in determining deteriorating work patterns.
3. Importance of firm and consistent application of standard corrective procedures.
4. Proper channels of communication with higher line authority, labor representatives, industrial relations staff, and EAP coordinator when supervisors are in doubt as to appropriate action.

Information about the existence of EAP and its purposes should be available for all employees, through an ongoing orientation program.

Job Performance

The advantages of the job performance approach are

Supervisor only evaluates performance.

Earlier intervention.

No new skills required.

Clear, simple policy for dealing with difficult problems.

Labor and management both share gains.

Significant cost benefits.

Benefits of EAP

The following are benefits of an EAP for both labor and management.

	Labor	*Management*
1.	Genuine personal benefits for members and their families.	Organization's demonstrated interest in the welfare of its employees is valuable to creating a good public image.
2.	Fewer grievances.	Fewer grievances.
3.	Fewer accidents.	Fewer accidents.
4.	Less money spent in disputes.	Less money spent in disputes.
5.	Improvement in morale of members.	Improvement in morale of members.
6.	Less absenteeism.	Less absenteeism.
7.	Decline in medical cost means a saving for the union.	Decline in medical cost because of accurate diagnosis of alcoholism and/or addiction.
8.	Better labor-management relations.	Better labor and/or management relations.
9.	Better relations among union members.	Cost saving: employee rehabilitation for fraction of the cost of a replacement.
10.	More referrals when program has credibility with union membership.	Effective approach to a problem heretofore ignored or denied.
11.	General educational effect of program for members and their families.	Reduction of stigma when a problem goes from the toolroom to the boardroom.
12.	Job saved.	Increased productivity.

MINING INDUSTRY SUBSTANCE ABUSE COMMITTEE

The Mine Safety and Health Administration (MSHA) academy in Beckley, WV, has received inquiries from various segments throughout the mining industry concerning alcohol and substance abuse in the mining industry. The Director of MSHA formed a committee to deal with these inquiries. The committee met in April 1985, at the mining academy in Beckley,

This committee expanded its membership to represent labor, management, and Government agencies affiliated with the mining industry, and national Government agencies dealing with alcohol and drug abuse. This expanded 18-member committee met for the first time in July 1985, at which time two cochairmen were elected. One was from management, the other from labor, to oversee the mining industry substance abuse committee.

At this point, the Mining Industry Committee on Substance Abuse, (MICSA) has spent considerable time on education by sharing information on the issues, and by calling in outside experts for advice and consultation. As this internal educational process has progressed, the committee has initiated several projects. First, the committee is developing a resource manual on substance abuse and employee assistance programs that can be used as models or guides by mine operators and/or labor unions. Second, the committee is assembling statistics on substance abuse, particularly as applied to mining. Third, the committee has commissioned an educational film, *Substance Abuse, Is It Our Problem.* This film, produced by MSHA, is an introduction to the problem of substance abuse in the mining environment. The basic thrust of the film is to encourage mine operators, labor unions, and miners to analyze their individual circumstances to determine whether a problem exists. Additionally, the film offers ways to deal with the problem, when it exists. Finally, the film invites the industry to request additional information from MICSA.

There is no single approach to substance abuse that will fit the need of every mining operation. Remedies must be site specific just as with any safety, health, or production problem. On the other hand, the mining industry has long been known for the ingenuity it brings to the problems of mineral extraction, transportation, and processing. There is every reason to expect that the same ingenuity can be brought to bear on substance abuse, and shared throughout the mining community.

MICSA's aim is to channel solutions derived from that characteristic ingenuity to those in the industry who seek to help employees in the mining environment who want to rid themselves of alcohol and substance abuse.

The MISCA's members have agreed on the following mission statement:

The Mining Industry Committee on Substance Abuse represents the combined efforts of labor, management, and Government. The mission of the committee is to make the mining industry aware of the problems resulting from alcohol and other drug abuse within the industry and to recommend possible methods to remedy the problem. The function of the committee is to assist the industry in developing programs and resources to recognize and provide help for troubled employees, and thus reduce the risk of accidents, lower absenteeism, and increase productivity.

SUMMARY

1. The concern about alcohol and substance abuse in the mining industry is there.
2. All organizations in the mining industry want to work together to solve the problem.
3. A method of addressing the problem will be presented to the industry in 1987.

FACILITATING SUPERVISORY PERFORMANCE: A WORKSHOP APPROACH

By Ronald Althouse[1] and James A. Peay[2]

ABSTRACT

Training may be regarded as the process of acquiring skills and knowledge for the performance of an activity. It is particularly important to organizations in terms of both resources expended on training and benefits resulting from subsequent performance. The effect of training in the mining industry is especially important because of widespread reliance on appropriate worker behavior to minimize the risks associated with mining processes.

The distinguishing feature of the training effort reported in this paper is its focus on assisting small-mine management in dealing with identified training needs for section supervisors and other supervisory personnel in day-to-day operations. Although the mining industry has had to absorb considerable responsibility for the initiation, modification, and continuation of training programs, the structural capabilities for implementing these programs seems to depend in part upon the size of the mining operation.

INTRODUCTION

The Bureau of Mines reports that more than 60 pct of the mining operations in the United States employ less than 50 people. Because small mines do not have the support personnel found in the management structure of larger operations, it has not yet been determined whether small mines have substantially different supervisor training needs. If consistent, useful training resources are to be fashioned, training needs and training environments for small mines have to be assessed.

The Mining Extension Service of West Virginia University (WVU) received Bureau support for the development of mine management training materials for small underground mines. Two functions were performed: (1) a need assessment and (2) curriculum development. Often, projects dealt with only one of these two functions, assessment or materials development. Benefits of the twofold program were that the designers would have a heightened awareness of the small-mine operation as well as knowledge of the potential audience, and at the same time, the materials would be relevant and could be assessed in the field.

The foundation for a sound assessment[3] includes: (1) sufficient communications to establish achievable and unambiguous objectives, (2) an analysis of the job to understand the skills needed to perform required tasks, (3) an evaluation of compatibilities (previous experience and/or capability measures) to help choose training media and allocate appropriate time for training, and (4) the identification of the limitations of the training program and the training environment.

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[3]Goldstein, I. L. The Pursuit of Validity in the Evaluation of Training Programs. Human Factors, v. 20, No. 2, 1978, pp. 131-144.

ASSESSING SMALL-MINE NEEDS

Characteristically, the small mines were comprised of a single conventional or continuous section crew; sometimes a mine operated two shifts. At times the mine operators managed the section; sometimes they did not boss. However, section responsibility for labor control and for factors affecting cost and quality were part of their experiences, and were not obscured by competing rules of discipline.

Repeated interviews with operators led to the formation of a set of commonly recognized operational and safety responsibilities (specific details of section foremen duties), which provided a measure for deciding what information to incorporate into the training materials. After supervisor task information was obtained through interviews, additional information was obtained from questionnaires sent to small mines.

Results from this assessment seemed to indicate that small mines have made limited training investments. They often lacked the know-how necessary to plan training programs and to improve safety programs. Moreover, small-mine operators felt that complying with State and Federal training regulations was costly, and they usually opted to minimized such costs by turning to outside training sources (e.g., private training, consultants, educational institutions).

On the other hand, attempts to identify priority needs for safety programs and training showed there was little clarity about the performance expected from supervisory personnel, and consequently, few objectives were identified by operators for training programs and information. The assessment revealed that other features of mine operations often regarded as perplexing to small-mine management dealt with labor relations, management skills, and engineering problems.

TRAINING RESOURCES

What training medium is appropriate for small mines? Classroom training was viewed unfavorably and considered highly impractical. Mine operators resisted programs that would interrupt production. Sending supervisors for training was considered to be such an interruption. Any problems dealing with know-how were solved in the context of the tasks at hand. Thus, many operators regarded easy-to-read informational guides as the best format for personnel.

While it was not feasible to deal with all the needs expressed by the operators, in many cases, the guides that were developed addressed more than one need. Seven guides were developed in a concise, learner-directed format, designed to be low in cost. They could be used as part of instruction on a topic or as a source of information for individual self-study. Written in a down-to-earth, straightforward manner, the content assists individuals in becoming more effective in their work. Brief descriptions of each guide will help to explain their scope and intent.

GUIDE NO. 1—HUMAN RELATIONS SKILLS AT WORK

This guide is designed to help mine supervisors deal with on-the-job human relations problems. Part 1 discusses human relations problems and the role of the supervisor. Part 2 provides practical suggestions for handling specific situations that often arise with miners on the job. Results showed that 68 pct of the mines had no human relations training for management, 92 pct were not currently conducting training, but 60 pct expressed a need to provide training at their mines.

GUIDE NO. 2—MANAGING A SECTION

Designed to help section supervisors carry out their duties effectively, this guide deals with the management of section crews for safety, operations, and compliance with Federal and State regulations. Useful information and tips are provided to assist supervisors with their duties and responsibilities. This guide was prepared in response to (1) labor management training needs—54 pct had not provided training, 92 pct did not provide training, yet 52 pct wanted this training; and (2) time management and/or planning the work day needs—72 pct had not provided training, 96 pct did not provide it, but 54 pct felt the training was needed at their mine. In many small mines, the section foreman was the only management level person normally inside the mine during the working shift.

GUIDE NO. 3—COMPLYING WITH PART 48

The guide provides an overview of Federal training programs. Included are mandated topics, training plan requirements and certification, a sample training plan, how to evaluate your trainer, and how to become a certified mine trainer. Because Federal regulations require that every mine provide training for all miners, the guide serves as a reference for small operators, providing a clearer understanding of the regulations and a means to achieving more benefit from training efforts.

GUIDE NO. 4—CONDUCTING YOUR OWN TRAINING

Mine owners and operators who want to conduct training are the target group for this guide. Topics include characteristics of the adult learner, how to develop useful learning objectives, instructional methods and using visual aids, and utilization of lesson plans. Setting up a training room, alternative delivery systems, and evaluating training progress are also covered. Emphasis is on keeping training up to date. Information showed that for more than half the mines, annual refresher training was conducted by private firms; only 40 pct conduct any of

their own training. As many as one-third felt they were not getting their money's worth from training investments.

GUIDE NO. 5—ELEMENTS OF MANAGEMENT PLANNING

This guide provides an introduction to managerial planning and control, and is geared to owners and operators of mines with relatively few management level people. Operations planning and control are described; part 2 relates control to planning, and it introduces tools of income and cash-flow management. Results indicated that many operators received little or no formal training in management practices, learning to manage operations through experience. Management training-educational assistance was one of the most often identified needs (89 pct).

GUIDE NO. 6—MANAGING MAINTENANCE

Managing maintenance draws on practical suggestions of mine operators, maintenance supervisors, electricians, and mechanics. Part 1 suggests steps for building an effective maintenance plan. Part 2 contains tips on carrying out maintenance and housekeeping procedures. Seventy-seven percent of the respondents indicated a need for an effective maintenance program, the highest rated on the assessment. In addition, maintenance problems were mentioned as the single, most salient problem in mine operations.

GUIDE NO. 7—DEVELOPING A COMPREHENSIVE SAFETY PROGRAM

Intended to help operators develop a mine safety program that is both mine-specific and comprehensive, materials deal with the structure and components of a safety program as well as ideas on how to evaluate specific needs and build a program that will be effective and reliable.

Few small mining operations had developed a formalized, documented approach to their safety and training efforts. By using the procedures and suggestions presented in this guide, operators can develop and institute a safety program suited to the particular needs of their mine and responsive to changes in mine conditions. This guide was systematically employed to link the rules and regulations for the *West Virginia Comprehensive Mine Safety Program* (WV Administration Regulations, Department of Mines, Chapter 22-4, Series 33) with operator reports submitted annually to the State by each mine. As a guide, its practical usefulness and scope as well as its basis for measuring safety performance and improvement is highly recognized on a statewide level.

STEPS TO IMPLEMENTATION

Mining Extension Service (MES) efforts to follow up on the uses of the new training resource showed two typical paths chosen by an operator: it was used (1) as supplementary handout material distributed during annual or mandated supervisory training, or (2) as reference material built into and supporting training on a topic. While the first avenue turns out to be an easy way to disseminate materials, results are inconsequential; a followup canvass dealing with 37 mine operations employing about 65 section supervisors showed that almost no one read these guides, and few even examined them to decide if anything useful was included.

Of the 33 section foremen contacted during the followup canvass, only 42 pct (14) were able to identify any one of three guidebooks provided to them (*Guide No. 1—Human Relations, Skills at Work, Guide No. 2—Managing a Section*, and *Guide No. 6—Managing Maintenance*). Nearly all of the section foremen contacted claimed these materials were helpful, yet only 9 pct (3) were capable of correctly identifying any content provided in the materials (e.g., planning equipment downtime, trouble-shooting, keeping on sights, conducting safety observations). Five reported they had given some material to other supervisors or associates, and nearly half (15) claimed that they had discussed some material contents with another supervisor since the training meeting when the guidebook materials were distributed. Nonetheless, there was little information from the followup canvass of foremen to support, in fact, that materials had been read, let alone used and discussed.

The second approach—using materials selectively as reference during training—was observed only twice, but had better results. *Guide No. 6—Managing Maintenance* was employed to help specify a high-priority management goal for the operators' mines. Specific procedures for supervisory performance on maintenance jobs were selected by the operator. However, the guidebook material was treated merely as a reference, without tailoring the objectives of their maintenance program to incorporate the content. In the authors' estimate, such use at least stimulated recognition of a need for maintenance planning and provided some suggestive procedures. Followup review showed that several employee participants did consult the material to gauge their activities and monitor experiences.

THE WORKSHOP IMPLEMENTATION

A third option emerged for exploring training arrangements. This process involved tailoring small mine's materials to allow each trainee to bring his or her own experience to bear on a set of problems.

This project was deliberately designed to address the needs of smaller mine operators located within a particular area. Called the Boone County Mine Management Training Project, it was administered by a committee composed of six mine operators. A key State and a Federal representative provided advisory assistance to the operators. The program was arranged to provide 8 h of training, organized into four 2-h sessions. It was available to every section supervisor or management person in the county. About 700 individuals were eligible to participate, of which 120 supervisory persons (roughly one-fifth) participated during the first two rounds of the workshop program. The following discussion focuses on these two rounds.

The overall training objective was to provide a vehicle through which mine supervisors could collectively identify, discuss, and share solutions to the problems encountered in day-to-day section operations. MES staff were committed to mobilizing resources, focusing areas of performance, maintaining continuity, and producing the workshop. In effect, the project was an implementation of a training protocol, based on a distinctive set of materials. The workshop plan was consciously guided by Goldstein's four-step assessment scheme.

A workshop format, rather than a formal classroom lecture technique, was used in the training sessions. The sessions were based on the premise that *problem solving is facilitated by problem recognition, and that answers are usually choices made from recognized alternatives.* It was felt that for every foreman who encounters a problem, there is another section foreman who has overcome a similar problem; therefore, supervisors could learn from each other. Learning how to recognize problems and how to examine alternative courses of action to mediate or overcome problems seems essential to any supervisory planning.

To invite active participation in discussions, an initial session was scheduled for each workshop group. By design, learning groups had to be a sufficient size to ensure a range of experience and still foster participation from each person. A format was needed that would inspire individual commitment to the efforts of the group. The procedure that was employed was to "nominalize" the group during the first session, and then to build on each group's specific experiences during the remaining four workshops. A nominal group process requires a small number of participants; each group was limited to 12 persons. Because foremen worked all shifts, morning, afternoon, and evening workshop sessions were organized on different days to accommodate mining operations. Arranging the participants into five groups satisfactorily met the size requirement. No group comprised more than two or three supervisors from any one mine operation.

The first session, when the nominalizing was accomplished, focused on responses to the instruction "Please list the most important opportunities for safely improving operations in your mine." Each participant listed as many opportunities as reflected on the experiences provided to him or her. A roundrobin followed and each member contributed until no additional proposals were forthcoming. The list was reorganized and condensed. Each participant was asked to select seven important safe productivity opportunities and to rank them from the most to least important. The 10 most important opportunities to safety improve operations were evaluated in three ways: (1) Difficulty (easy or hard to do), (2) frequency (frequently or seldom encountered, and (3) availability of needed resource or skill. All participants were asked to consider the priorities to reassess tactics discussed, and to begin the following session based on outcomes of the meeting. Each operator whose supervisors had participated received a copy of all workshop results. Each of these operators was asked to rate the list and to assess the listed recommendations concerning implementation.

By using results from the initial session, illustrative material was chosen to focus on in the four subsequent meetings. The program finally selected was the following:

Week 1.—*Establishing efficiency on the section*

A. Consider value of effective planning

B. Develop a work system whereby duties and tasks function in unison

C. Anticipate and utilize downtime effectively

D. Foresee problems and limit their impact

Resource: *Guide No. 2—Managing a Section*
Guide No. 6—Managing Maintenance

Supervisor Responsibilities: Operating, Safety, and Compliance (see Appendix)

Week 2.—*Human Relations*

A. Review principles of human relations

B. Motivate the workforce

C. Resolve disputes and conflicts

D. Earn the respect of the workforce

E. Give each worker the responsibility of his or her job

Resource: *Guide No. 1—Human Relation Skills at Work*

Week 3.—*Safety roles and responsibilities of the section supervisor*

A. Set the standards for safety on the section

B. Provide a good safety example through own work habits and practices

C. Control and/or eliminate safety hazards on the section

D. Assure compliance with company policies, Federal and State regulations

E. Analyze accidents and take proper remedial actions

Resources: *Guide No. 4—Conducting Your Own Training*
Guide No. 7—Establishing a Comprehensive Safety Program
Supervisor's Jobs—How Risky Are They? What the Stats Show. (MSHA Magazine Winter-Spring 1984.)

Week 4.—*Understanding State and Federal Regulations*

A. Keeping up to date on regulations

B. Knowing what the inspector expects on your section

C. Keeping your required records up to date

Resources: *Code of Federal Regulations* (30 CFR)
West Virginia Mining Bulletin
West Virginia Mining Laws
West Virginia Administrative Regulations

USING GUIDEBOOK MATERIALS

Several examples illustrate how these resources were meshed. Performance improvement efforts were specifically focused upon during the workshops. Thus, for example, an examination of results from the initial session suggested that understanding State and Federal regulations was essential to compliance goals and objectives. It was decided to provide each person with 30 CFR, *West Virginia Mining Bulletin, West Virginia Mining Laws*, and *West Virginia Administrative Regulations*. In regard to safety and compliance goals, an attempt was made to break out of the lockstep mold of "token compliance" to regulations. Supervisor-foreman safety and the proposed tactics for loss-prevention and damage control (i.e., direct and indirect costs) were examined. These concerns were condensed into a set of materials for one session.

Practical features of foremen responsibilities and their dealings on the job were taken from practical applications. A lead-in discussion focused on the authority of section foremen. Foremen know they are responsible for production on their section and are held accountable for the safety of workers assigned to them. On the other hand, they express varying degrees of awareness and understanding about company policies that must be followed. Experience shows that foremen are results oriented; consequently, they may do their work without attention to subsystems or practices that could aid them.

One useful example focused on a section foreman whose shuttle car operators were running on damp, soft roadways. Past experience and present demand naturally informs the foreman that the roadways must endure for at least 1, maybe 2 weeks. A few days later, the section has unnecessary downtime for shuttle car tram delays. The foreman must now explain to the mine operator the reasons for downtime for shuttle car tram delays, as a result of ruts in the roadway. The operator knows that conditions on the section should not have resulted in these delays.

In small-mine operations, work procedures are not usually based on articulated planning. Most loss-prevention and damage-control analysis can show that both employee exposure to hazards as well as equipment breakdown are among the outcomes associated with lack of planning. However, the foreman may not have been prepared to control the situation by monitoring conditions of roadways, by avoiding travel over the same tracks, or by advising operators to fill developing ruts. The effect of failing to anticipating these conditions usually is an increase in management errors. There are no plans of action to combat conditions, to direct the operators to adjust their actions, nor to control the developing situation.

A second dimension of the workshop focused on the responsibilities of management to support its supervisory personnel. Operational practices need to be tailored to an organization, detailed, and fully imparted to personnel who must use them. Anticipation, planning, task support, and management interaction are persistent features of coordination. More complicated jobs entail more thorough planning. The foreman is involved in arranging resources, organizing tasks, and scheduling work events. He or she has to coordinate other workers to supplement labor. Above all, he or she has to anticipate how to control, step-by-step, the rate of task and/or job completion in spite of changing conditions, equipment breakdown, or other developments that can impede work. Assessment of actual versus planned steps is made, and correction actions need to be anticipated to keep on schedule. Knowledge of the jobs to be done, how they need to be done, and when they need to be finished is essential to the foreman's mission.

Section foremen are instrumental in controlling daily output and are pivotal in maintaining good labor-management relations. To secure the consent of workers to perform their work according to preferred procedures, the foremen must be consistent in performing their jobs. They need to plan section moves and anticipate delays that result from deteriorating conditions or equipment failures. Supervisor demands will need to fit those performances that can be realized by workers. The foremen must be consistent in their own expectations, in training their personnel, in assigning tasks fairly, in "keeping pay," and in ensuring safety. Their authority can be exercised when their leadership is acknowledged by the crew; leadership is acquired after consistent management is demonstrated.

Throughout the workshop the participants were able to examine procedures, their successes and shortcomings, and points of change in practices. Self-check lists for supervisors are useful when coupled with performance feedback (daily, weekly, and monthly production and downtime reports, grievance status reports, accident and citation summaries). Examples of self-checks were shared and criticized in the workshops. The prime objective of self-checks is to force ongoing comparison between actual and planned performance. The information is useful to formulate preferred ways to achieve operational objectives.

SECTION SUPERVISORS' RESPONSIBILITIES AND AUTHORITY

Each participant had been provided with a list of supervisory responsibilities, organized according to operating, safety, and compliance duties (appendix). It was possible, therefore, to direct attention to common expectations and to the competing and conflicting demands frequently experienced by section foremen in performing their jobs. Moreover, by recognizing responsibilities and what actions occurred during preshift, start-of-shift, on-shift, end-of-shift, and post-shift operations, concern was focused on planning and communicating skills. Foremen were urged to examine the list to determine which duties were routine or not, which were easy or hard to do, and what authority was required to gain consent or secure compliance. This permitted each workshop group to contrast current practices against proposed improvements and upgraded performances.

One strategy for improving section supervisor performance is to arrange duties in chronological order spanning a typical production shift, directing attention to the way foremen must perform and the way they think about their jobs. In small mines, one- or two-section operations, it is precisely such information that is often informally, and sometime quite haphazardly, gathered. Presumption and habit dominate in these operations. The process forces supervisory personnel to match and contrast personal practice with preferred performance.

The *initial phase* of work, before the shift begins, finds the foremen gathering information from the previous shift to determine the needs of the upcoming shift and formulating a work plan. Based on this plan, they check the status of resources and arrange resource availability on their shift. They coordinate their section plans with the general

foremen or other production, maintenance, and staff managers. They monitor the check-in of crew members and obtain fill-in labor as needed.

At the *start-of-shift*, the foremen make an inventory of section conditions, equipment, resources, and operational readiness on arrival at the section. Crew members assist the inventory. Any significant revisions in the workplan depend upon the accuracy of observed conditions. The foremen initiate required section examinations simultaneous with the inventory, before face operations begin. The tempo for the rest of the shift's operations is set at this time.

Operations comprises the bulk of the foremen's shifts. Production cycles typically bring into coincidence several of their duties and produce overlapping responsibilities that are managed simultaneously. These responsibilities pertain to

1. Operations, including production, maintenance, and downtime.
2. Compliance with State and Federal mining laws.
3. Health and safety of workers, including training.
4. Labor relations, including communication and administrative accountability.

The foremen are the keys to exercising labor discipline and to securing its consent to authority; they are essential to maintaining a smooth running operation. They monitor the flow of work throughout the shift and direct cycle-by-cycle adjustment in face operations. They must effectively plan ahead of face operations but keep up with routine regulatory duties as well as abnormal disturbances.

Ensuring that work gets done safely is a weighty responsibility for the foremen. There are always convenient ways to get a job done easier than preferred work practices, but shortcut ways usually are not safe. Not every way to reduce the work effort is hazardous, yet many shortcuts are known to increase risk of exposure or injury to oneself or a coworker.

Cross-analysis strategies can be used to restructure experience into chains of events that encourage anticipation and planning. Because miners must learn to mine coal safely, they can be taught *preferred* safe work procedures, and they can learn to correct those actions that get them into trouble.

At the *end-of-shift*, the foremen execute a routine thorough shutdown of the section, complying with regulations, controlling physical and equipment conditions, and fully coordinating with oncoming shift supervision. The *post-shift* is used to wrap up the day's activities. The foremen's work includes accurately reporting production, downtime, and ancillary work completed. They process pay sheets for employees, coordinate with the oncoming shift, and indicate resource and equipment repair requirements. They identify operating problems warranting attention in the future (immediate, intermediate, and longer term plans) and they complete all reports in official record books. Before finishing their day, it is important that the foremen follow up on any promises made to an employee.

BENEFITS OF EFFECTIVE TRAINING

The primary objective of the workshop program was improvement of frontline supervisor performance under varying situations. Gains would afford better operations, thus improved safety and productivity of the section crew. These goals can be achieved by section foremen who master management techniques, tactfully exercise authority, and possess the know-how to execute responsibilities.

Resulting benefits (i.e., measures) include (1) improved control of section operations, (2) more consistent compliance with mining laws, (3) reduction of unnecessary delays to production, (4) reduction of accidents and lost employee-days, (5) reduction in the number of employee grievances, (6) decrease in absenteeism, (7) improvement of crew motivation, (8) better teamwork and unified accomplishment of common goals, (9) better crew preparedness in responding to critical situations, and (10) continual progress toward improving the mining system.

A reactive, hit-and-miss approach to foremen development occurs too often and fosters operations in which foremen expend their energy trying to stay out of trouble. Preparation of section foremen reduce their vulnerability to inexperience as well as inadequate knowledge of the requirements of their jobs. When foremen are unprepared, they are prone to make decisions that can and do jeopardize operations and subject them to criticism from their crews. The building of an operation that encourages improved performance results in a better chance at achieving success.

DISCUSSION OF THE WORKSHOP EXPERIENCE

At the time the workshops were being conducted, the coal mining industry was undergoing considerable realignment among management-supervisory personnel, and was experiencing many mine closings. Section foremen as well as working miners were confronted with the ultimate dictum of discipline—choosing between work and no work—and were directly impressed with the fact that production was essential to keeping a job. As a matter of fact, during workshop sessions conversations repeatedly drifted to talk about record production, although fewer miners were employed than in the recent past. Moreover, each of the small mining operations from which the workshop participants were drawn was operating with a bonus-incentive wage program. Each operator reported that in addition to incentive, their employees were paid top wage scale. Thus, for these operations, production assured bonus, and bonus was normally attainable with a fairly high degree of certainty.

In these small mining operations, section foremen were in the same boat as their miners with regard to continuing employment. Confronted with dwindling employment options and attainable, although high, production goals, but boosted by incentive wages, foremen and workers found considerable inducement to collaborate and achieve consistently high output. These supervisors were aware that unless the mine operators who employed them endorsed any of the techniques and procedure addressed in the workshop materials, they would not be accountable for

any new proposals. The study observations, quite frankly, suggested that there was little reason to expect the section foremen to change any ways of action at their mines unless explicitly directed to do so by the operator. Where training was largely regarded as cumbersome regulation, typically assigned to peripheral personnel or outside contractors, workshop materials were not approved and options were disregarded.

The situation was oftentimes different for foremen drawn from larger, more complex mine operations. In the larger firms, organizational forces produced different vulnerabilities for section foremen. Job rivalries put them into situations in which their own equals were heavy competitors; when realignments hit, who did or did not stay depended on what "appeared" to foremen as discretionary actions by layers of management above them. Their own production crews attempted to get greater latitude (e.g., taking shortcuts), so they felt they were working harder than ever to keep up production. Because mine operations management was likely to tighten demands, they also felt they were obliged to make greater investments in retaining their positions. Moreover, there was visible evidence of threat to their security: bosses who had attained ranking positions (e.g., shift bosses) were back on production sections. Based on a number of followup contacts with foremen from several large mines, a strong inclination toward disengaged participation in workshop activities was found: participation was an assignment, and attendance in the workshop produced the marginal investment (compliance) that at least protected them from exposure to management.

In larger mines, where full-time specialists are charged with the responsibility to obtain appropriate behavior from employees engaged in the mining process, "property rights in materials" are very likely to be highly protected, vested interests. The workshops inadvertently invaded that training territory, precisely at a time when job security was a tender issue for many staff employees. Secondly, and correctly, most of the company operations had corporate-approved training programs geared to their firms. Training was planned and executed by the company, providing foremen with information that invested responsibility as senior management deemed appropriate: in these programs there was no outside interference with their proposals and concomitant procedural rules.

The workshops potentially legitimized information (e.g., the comprehensive safety program) and procedural guides to actions (e.g., grievance or accident investigations, loss-prevention) that contrasted, sometimes conflicted with company rules. It was learned also through followup contacts with management, that rules are made and orders given to foremen, that are not arrived at through discussion. But is is also realized that management training programs now in use were produced to handle newcomers to the ranks of frontline supervision during a period of industry expansion. These materials reflect poorly the operating conditions of the industry today and veteran supervisors may not find them useful at all.

There is no reason to expect new departures in operating practices as a result of these workshops. They were immeasurably more effective in reaching supervisors, or gaining attention from them for a short period of time, than other distribution techniques seen elsewhere. Depending upon the immediate degree of success personally experienced by the supervisor, certain elements of the workshop could be diffused among the supervisory workforce. Ways to attack maintenance or housekeeping problems, to curb downtime, to deal with comprehensive safety efforts, and to reflectively plan by anticipating preferred performance and action from miners on their sections did, indeed, catch the attention of participants.

These workshops were supposed to be building blocks for a continuous training model that should have been incorporated into the Boone County Mine Management Training Program. When management commitment dwindled, continuity eroded for the workshop program.

CONCLUSIONS

While the small mines management training project chalked up several accomplishments, it also experienced a share of shortcomings—some were dealt with but others lingered and even grew worse with time. First, the workshop may be a more viable technique for smaller operations than for larger operations; at least, this was the experience. Second, there was a remarkable variety of experience and capabilities among section foremen, which lead to a concern about *prerequisite skills* (e.g., mapping, print reading, hydraulics, job instruction training abilities). Another consideration was redundancy and distraction; future training and the selection of problems to study would have to be based on much more precise performance results, using proven strong programs or procedures as criterion. Fourth, followup on the consequences of the training was difficult—some followup was attempted, but actual outcomes depended heavily on the operations, and there was no assurance of adoption or implementation. Finally, when committee support eroded, the program was difficult to maintain; if management support was strong, participation endured.

A measure of the relevance, if not the success, of the Bureau-sponsored small mines management project is evident in the fact the Mine Safety and Health Administration (MSHA) has packaged and is distributing the entire package of materials as well as the workshop curriculum, virtually without change or modification of the Boone County program, as *Industry Supervisory Training*.

APPENDIX.—LISTING OF SECTION SUPERVISOR DUTIES

I. Preshift Duties

1. Arrive 1 h early to allow ample time for good coordination.
2. Dress immediately to avoid interference with coordination later.
3. *Read* over previous shift reports for production, maintenance, examinations, violations, and supply requisitions for your section.
4. *Get report* on pagerphone from on-shift foreman regarding—
   a. Status of equipment-maintenance work needed.
   b. Equipment locations in the mining cycle.
   c. Status of physical conditions and/or operational problems.
   d. Work that needs to be accomplished.
   e. Compliance problems.
   f. Employees staying in between shifts for any reason.
   g. Signature of mine examiner book with report.
5. *Monitor* check-in of personnel.
6. *Convey status* of section to shift foreman; coordinate on-shift requirements.
7. Make request for extra or temporary employees.
8. Make sure crew members are properly equipped (clothing and tools).
9. *Communicate* conditions on sections to crew members.
10. *Coordinate* at mine map with previous shift section foreman, shift foreman, mine foreman, and superintendent. Discuss important matters openly.
11. *Notify* extra or temporary personnel of job assignment and if special equipment is needed.

II. Start-of-Shift Duties

1. Ensure entire crew catches mancage as scheduled.
2. *Check* mantrip for all safety and operational requirements.
3. *Check* safety of crew on mantrip—
   a. No body parts outside mantrip.
   b. Operators outside mantrip wear glasses.
4. Start inby to work section (calling dispatcher as required).
5. Travel at safe speed, at proper distance, and in full control.
6. *Note* unsafe road, roof, rib, support conditions and report to shift foreman and/or dispatcher.
7. Keep haulage switches in proper position on the way into section.
8. Deboard in a proper and safely guarded place.
9. Have mantrip parked at designated place.
10. Ensure walkway is well kept and safe.
11. Give safety talk, if proper time (weekly).
12. Check roadways and intersections on the way to first face for roof, rib, and floor conditions, rock dusting, cleanup, and dustiness.
13. *Examine* working faces for—
    a. Deenergized equipment and location.
    b. Air quantity at inby end of brattice and/or tubing.
    c. Condition of ventilating checks, brattice and/or tubing.
    d. Methane, roof, rib, and floor conditions.
    e. Safety and compliance.
    f. Conditions that need correcting (and *note* them).
    g. Supplies on equipment.
    h. Sight lines.
    i. Cleanup and dustiness.
    j. Necessary cycle moves (fan, cables, stopping, etc.).
14. *Give instructions* to crew members as needed; note revisions to initial plan and conditions requiring caution in correctng them.
15. Determine status of equipment, cables, materials from crew members who checked them in a general way.
16. Set power on equipment if ready and operable; begin repair of equipment that is not operable and coordinate for additional mechanics and/or electricians as needed.
17. Coordinate dumping of supplies that are loaded during face run; ensure adequate amounts were loaded; load any necessary unplanned for supplies; check servicing of equipment.
18. *Report* any unplanned occurrences to shift foreman and/or dispatcher.
19. *Record* the nature and duration of unplanned occurrences (delays).
20. Give task training and/or description of escapeways and firefighting duties to temporary or extra personnel. Practice safe performance of tasks as necessary.

III. On-Shift Operational Duties

A. Production Related Cycle

1. *Monitor* initial move to first cut; ensure sight line is in and used; ensure extra brattice-ventilation tubing, spads, wire, tools are ready; ensure shuttle car operators use correct haulroads (closest changeout) and have enough cable for entire cut. Ensure personnel are coordinated on plan.
2. Monitor loading of first couple of shuttle cars to ensure smooth start and note any problems (physical, operational, or mechanical).
3. *Report* start time to dispatcher, also state probability for loading well and anticipated problems.
4. Return to cut before time for place change and coordinate move. *Note* any changed conditions and give warnings to workers who will enter places, if necessary.
5. Plan ahead for cable moves, fan moves, keeping up with sight lines, cleanups, rock dusting, etc. Coordinate as necessary.

6. *Report* any problems or needs immediately to dispatcher and shift foreman.
7. Repeat steps 1 through 6 for each cut when possible.
8. Keep track of all delays to production immediately and accurately for use on shift report.

B. Health and Safety Actions

1. Monitor crew members in the performance of their jobs and ensure safe work practices are used faithfully. Follow up with reinstruction as needed.
2. Ensure workers use proper attire and safety equipment and tools for conditions encountered.
3. Ensure workers use proper tools and equipment for job and also properly operate them.
4. *Observe* workers for inconsistent performance and possible drug or alcohol effects. Counsel with discretion privately, as necessary. Personal problems may also affect performance.
5. Use caution and give warnings in a new or rare situation; observe closely for hazards and anticipate supplemental actions that may be needed to combat the hazards.
6. Ensure employees report all accidents, equipment damage, and close calls. Report them, in turn, to shift foreman at appropriate time.
7. Ensure that an injured employee goes out if serious injury is possible. Call dispatcher to arrange transport.

C. Labor Relations Practices

1. Maintain control of operations; provide steady and consistent direction of workers.
2. Communicate with workers and other managers; inform workers of actions and decisions; coordinate with workers and managers for fulfilling needs of section.
3. Do not participate in spreading gossip.
4. Respect abilities of workers and solicit their input on specific tasks.
5. Talk over incipient grievances privately; sort out details and try to settle in accordance with contract. Talk over personal problems with workers who seek help.
6. Ensure accurate and timely paydays for workers.
7. Keep track of contract leave days and unexcused absences for crew members, caution them privately and tactfully regarding indiscretions, and remind them of disciplinary provisions of contract.
8. Keep alert and energetic. This mental conditioning rubs off on workers.
9. Equitably assign extra and downtime jobs to workers.
10. Make only promises you know you can keep, follow through promptly and accurately on them; be fair to all crew members.

D. Compliance Actions

a. Ventilation-Escapeway Provisions—Daily
1. 20-min methane examinations at working faces.
2. Examinations at faces every 2 h.
3. Air readings at faces and returns.
4. Mine examiner report on section following examinations.
5. Ensure escapeway signs and directional markers are up.
6. Ensure adequate rock dust maintained in escapeways and rest of section.
7. Ensure escapeway map is up to date on section.
8. Ensure dust control methods are maintained—
   a. Sprays on equipment.
   b. Roadways wetted if necessary.
   c. Equipment washed down.
   d. Belt tailpiece and feeder maintained.
9. Keep water pumped down on section.
10. Maintain brattice and/or tubing within 10 ft of face.

b. Roof Control Provisions—Daily
1. Ensure bolting pattern is maintained within tolerance.
2. Use supplemental support as conditions warrant.
3. Ensure "1 of 10" and "1 of 4" bolt torque checks are made.
4. Ensure temporary roof support on bolting machine makes contact with roof.
5. Ensure posting and cribbing patterns are maintained on pillar extraction, watch for changing conditions.
6. Use wooden headers on bolts for greater bearing surface when needed.
7. Maintain sight lines to ensure consistent pillar sizes.
8. Use rib support where needed.
9. Maintain longer bolts and posts on section.
10. Check roof by drilling one hole 1 ft longer each cut.
11. Ensure maximum cutting width is not exceeded.
12. Ensure sum of diagonal distances at an intersection is less than maximum allowable distance.
13. Report unintentional roof falls for investigation and mapping; rehabilitate according to posted plan.
14. Discard resin that exceeds shelf life immediately.
15. Follow intersperse pattern for change from resin to conventional bolting, and vice versa.
16. Do not exceed cut depth.
17. Follow plan for recovering supports during pillar extraction.
18. Ensure proper tools are available (sounding device, torque wrench, slate bar, etc.).
19. Follow cut sequence within tolerances.

c. Electrical-Permissibility Provisions—Daily
1. Ensure equipment plugs and receptacles at power center are marked and matched.
2. Ensure restraining clamps or chains are on trailing cable.
3. Ensure warning signs for high voltage are up.
4. Ensure necessary rubber mats are in place at power center breakers.
5. Ensure permissibility is maintained for equipment, pumps, heaters, etc.
6. Ensure temporary splices are fixed before next day and no temporary splices exist within 50 ft of a machine.
7. Ensure all bonds are installed on rails along track (rail-to-rail, cross bonds 200 ft, switches).
8. Watch for arcing between machines.
9. Ensure cables are hung and guarded where needed.
10. Keep equipment clean.
11. Maintain fire extinguishers and rock dust (240 lb) at permanent electrical installations.
12. Ensure equipment is safe to run (guards, etc.).

13. Ensure end of trolley wire is secured and guarded.
14. Ensure trolley wire is guarded at mandoors and mantrip unloading stations.
15. Use insulated hangers for hanging cables.

d. Miscellaneous Provisions—Daily

1. Ensure workers are fully task trained and it is documented.
2. Ensure accumulations of coal and dust are cleaned up.
3. Ensure two sources of communications are working properly.
4. Ensure portable water is maintained on mantrip and in section.
5. Ensure ample first aid supplies are available.
6. Maintain clean and unobstructed walkways.
7. Ensure manholes are cut as required along track.
8. Ensure workers keep self-rescuers with 25 ft and self-contained self-rescuers are available on section.

e. Weekly Provisions

1. Make necessary bleeder station examinations and enter in report book.
2. Ensure weekly permissibility examinations are completed for all equipment on section and properly documented.
3. Ensure methane monitor calibration is completed and documented.
4. Conduct safety meeting and document it.

f. Monthly Provisions

1. Ensure smoking articles check is made and documented.

g. Quarterly Provisions

1. Ensure escapeways are walked and documented.
2. Ensure fire drill is conducted and documented.

h. Annual-Semiannual Provisions

1. Ensure 8-h retraining is given to personnel.
2. Report any ideas for revisions to roof control or ventilation plans.

IV. End-of-Shift Duties

1. Stop cutting in sufficient time to leave section in full compliance with mining laws.
2. Leave section in good condition for next foreman; report all problems fully and accurately (equipment down, poor conditions, etc.).
3. Do not leave section early—you are finishing cutting or moving too early; economic survival may someday depend on extra 10 min of operation.
4. Ride out in mantrip as you rode in—orderly and controlled.
5. Ensure no horseplay occurs at cage or elevator, which can injure workers.

V. Postshift Duties

1. *Make* out shift report professionally and completely.
2. *Coordinate* with mine foreman and superintendent at mine map; report workers left in, labor relations problems, and operational problems; mark section map up to date; identify near-term section needs such as power center move, track advance, planking, stopping, belt move, etc.
3. Fill out paysheet accurately and place in proper distribution box.
4. *Coordinate* with maintenance regarding any mechanical problems, even if small.
5. *Fill out* and sign mine examiner and assistant mine foreman books.
6. *Fill out* and sign additional report books as required (smoking articles check, safety talks, bolt torque, bleeder station examinations, escapeway travel, fire drills).
7. Perform any followup promised to crew members.

THE HECLA STORY: ORGANIZATION DEVELOPMENT IN THE HARD-ROCK MINING INDUSTRY

By Cecil H. Bell, Jr.[1]

ABSTRACT

An organization development (OD) demonstration project, sponsored by the Bureau of Mines and conducted at Helca Mining Co., showed that OD techniques can improve mine safety and productivity. One year after the program began, lost-time injuries had decreased 44 pct at the target mine and decreased 8 pct at a comparison mine. No effects on productivity were observed at that time. After the program was in operation at the target mine for 5 yr, lost-time injury rates had declined by 78 pct, short tons per stoping worker shift had increased 54 pct, and short tons per worker shift for all labor had increased 32 pct. It is reasonable to attribute some of the improvement in performance to the OD program. Team building-problem solving meetings at all levels of the organization constituted the principal OD technique used in the program. Company members have been trained to conduct these meetings. This paper describes the OD program, evaluates its effects, and presents observations on the relevance of OD for the mining industry.

INTRODUCTION

In 1979, the Bureau of Mines sponsored the first organization development (OD) program ever conducted in the metal-nonmetal mining industry in the United States. The objective was to determine whether OD techniques could improve mine safety and mine productivity. The project was accomplished under Bureau contract J0387230, in cooperation with Hecla Mining Co., Wallace, ID. That demonstration program, now in its seventh year at Hecla, showed that OD techniques can improve both mine safety and productivity. This paper describes and evaluates that project.

OD is a process for causing organizational improvements based on the belief that organization members themselves can identify and solve their major problems, if they use systematic procedures guided by an outside consultant. In OD, organization members examine how well they are doing and look for ways to do better.

Hecla Mining Co. was founded in 1891 and describes itself as "the premier silver mining company in the United States." It is usually the foremost producer of newly mined silver in the Nation. When the project began in 1979, Hecla had about 700 employees, operated two major silver-lead mines in the Coeur d'Alene district of northeastern Idaho (the Lucky Friday Mine and the Star Mine), and had several smaller operations in other Western States. Mr. William A. Griffith, president and chief executive officer, agreed to participate in the Bureau's project in order to improve mine safety.

In broad outline, the Hecla program unfolded as follows: the Bureau sponsored the OD demonstration project from July 1979 to May 1982, during which time the emphasis was on improving mine safety. The target mine was the Lucky Friday Mine, and 1981 was the period of greatest activity at the Lucky Friday. The work tasks of early 1982 consisted of completing the demonstration project and writing the final report for the Bureau. In May 1982, Mr. Griffith asked the Bureau's contractor to "continue the OD program and train our people to do what you do."

The period since 1982 has been devoted to consolidating the program at the Lucky Friday Mine, extending the OD effort to encompass other organizational units, and training company members to conduct the program. Many changes have occurred at Hecla since the OD program began. In 1981 Hecla acquired Day Mines, Inc.; in 1982 mining operations at the Star Mine were discontinued; and in 1984 Hecla acquired Ranchers Exploration and Development Corp. The company had 945 employees at the end of 1985.

Although OD is used extensively in many industries, there have been only a few OD programs in mining, all of them with coal mining companies. The most noteworthy OD program in mining was the Rushton Coal Mine project conducted by Trist, Sussman, and Brown (*1*),[2] using sociotechnical systems theory. According to these authors, the results of the 4-yr program were a reduced number of lost-time injuries, improved safety practices, decreased

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[2]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

production costs, and increased productivity. The program was terminated prematurely, however, when the union membership voted to discontinue it. An independent analysis of the Rushton project by Goodman (*2*) concluded that the effort produced "slight positive gains" in safety and productivity, but not the substantial improvements reported in reference 1. Gavin and Kelley (*3*) conducted a multiyear OD program in a Colorado coal mine and reported improved employee attitudes and morale as well as increased ability to deal with work-induced stress. In summary, OD programs in coal mining have been few in number, but have usually produced positive results.

The overall strategy and implementation activities of the OD program are presented in the next section. Then the results are examined. Finally, conclusions are suggested and implications for the mining industry are proposed.

OVERVIEW AND DESCRIPTION OF THE OD PROGRAM

This section presents the elements of the OD program strategy and a chronological history of the highlights of the project.

PROGRAM STRATEGY AND GUIDING PRINCIPLES

The goal of the demonstration project was to improve mine safety and productivity; OD techniques were the means, and the time frame was 3 yr.

The program strategy was developed after several months of orientation and diagnosis by the consultant team, during which time they learned about the organization's strengths and weaknesses, its preferred modes of operating, and its culture and values. The program strategy, developed jointly with the president and senior management team, included the following key elements:

Conduct a classic OD program.

Make team building-problem solving the principal OD technique used.

Use additional OD techniques as appropriate.

Start at the top of the organization and work downward through the hierarchy.

Include hourly employees and their supervisors in the program.

Establish and maintain high program momentum and extensive consultant involvement.

Avoid a one-shot, quick-fix program.

Focus on task accomplishment; that is, getting the job done.

Address safety issues at all levels of the hierarchy.

Conduct the program at a "treatment" mine and designate a "control" mine to receive no treatment.

Be successful; do not get fired.

Conduct a Classic OD Program

A classic OD program has the following characteristics: it is a long-term effort; it is conducted by an outsider who is trained to understand organizational dynamics and know how to change them; the intervention plan is developed and implemented based on a thorough diagnosis of the organization; primary emphasis is placed on examining and changing the culture and processes of work teams to help them function better; considerable effort is spent working on real, high-priority problems and opportunities; and such programs are deliberately consultant-intensive.

Make Team Building-Problem Solving the Principal OD Technique Used

Classic OD programs follow the problems wherever they lead, and OD interventions are developed for the problems identified. That was done at Hecla. Additional interventions used were: individual coaching and counseling; individual and team goal setting; safety experiments and analyses; first-line supervisor training; behavior modeling skills training for middle managers; intergroup problem solving and conflict resolution; role analysis and clarification; operations management studies; a goal setting-performance feedback experiment; performance appraisal training; OD facilitator training; and team problem solving skills training for line managers.

Start at the Top of the Organization and Work Downward Through the Hierarchy

Successful OD programs are managed from the top (*4*). Hecla's president not only managed the entire program, he gave it strong support and was actively involved as a participant. Team building meetings began with the president and senior management team and progressed down the operations department to include the vice president for operations and the operations team (which included the mine managers), the Lucky Friday mine manager and the mine top management team, the Lucky Friday mine manager and mine production team (which included first-line supervisors called shift bosses), and approximately one-half of the hourly employees. This downward progression ensured that each team leader had already been involved in team building meetings at a higher level, knew what to expect from the meetings, and was comfortable with the team building process.

Include Hourly Employees and Their Supervisors in the Program

Safety and productivity ultimately occur where the pick hits the rock; therefore, the program had to include the shift bosses and crews. Attitudes and behaviors had to be changed at that level, but encouraged and supported by higher levels.

Establish and Maintain High Program Momentum and Extensive Consultant Involvement

Successful OD programs have a sense of momentum, excitement, and accomplishment that is established early and maintained throughout. Early successes are sought that will spark this sense of progress. The diagnostic interviews got the momentum started. Next the consultants designed a new performance appraisal system, trained all the raters who would use it, and the system was implemented. Team building meetings were always launched

with a series of meetings held in rapid succession to promote quick, positive results. As soon as team building was established at one level, it was extended to the next level to promote a sense of urgency and progress. The consultants made frequent visits to the company: 9 in 1979; 17 in 1980; 23 in 1981; 14 in 1982; 19 in 1983; 19 in 1984; and 10 in the first 6 months of 1985. The high level of consultant participation signaled that the program was important, serious business.

Avoid a One-Shot, Quick-Fix Program

From the outset, the president was adamant about the nature of the program. The program was for real, not an academic exercise; it was intended to produce permanent improvements, not quick fixes. The program was to instill better ways of managing, not flashy superficial behaviors that would be discarded when the program was over. The president insisted on a solid, deliberate program, realizing it would require hard work by everyone.

Focus on Task Accomplishment, That is, Getting the Job Done

Team building can be task oriented (getting the job done better) or interpersonal relations oriented (getting people to like each other better) or a combination of both. The focus at Hecla was on task accomplishment, not interpersonal relationships. A task focus was chosen because it is less threatening to people. It is a more natural and legitimate activity in work organizations and, when task accomplishment is improved, interpersonal relations usually improve as a byproduct.

Address Safety Issues at All Levels of the Hierarchy

Mine safety is a complex, multidetermined phenomenon. The attitudes and behaviors of the workers are important, but so are the attitudes and behaviors of management. Incentive systems, working conditions, organizational culture, individual habits, and managerial practices all influence safety. Each team addressed the question of what it could do to improve mine safety. Naturally the answers differed, but teams at all levels implemented specific actions to improve the safety record, and these actions had a cumulative, long-term effect on injury rates.

Conduct the Program at a "Treatment" Mine and Designate a "Control" Mine to Receive No Treatment

The OD program was given to the Lucky Friday Mine and withheld from the Star Mine, thereby creating an experimental-control group research design. This allowed effects due to the program to be inferred more easily. Selection of the Lucky Friday Mine to receive the treatment was done on a nonrandom basis. The Lucky Friday was considered the more difficult mine to work with because it had problems of low morale, a poor safety record, anticompany attitudes, and was a unionized mine. However, if the program were successful, the benefits would be greater because the Lucky Friday was a richer mine than the Star.

Be Successful, Do Not Get Fired

This guideline was developed by the consultant for the consultant. This was the first time OD had been tried in hard-rock mining, and it could well be the last opportunity for a long time if the program were a failure. It was about equally important to be successful, that is, improve mine safety, as it was to avoid failure, that is, have the program terminated before it was completed. The program had to be valuable for the company; the consultants had to be competent, relevant, acceptable, and results oriented. The consultants worked especially hard to ensure that diagnoses were accurate, that interventions were timely and well executed, and that the necessary formal and informal communications between clients and consultants took place.

In summary, these were the key elements of the program strategy conceived prior to launching the intervention and implemented during the program to guide decisions and choices.

CHRONOLOGY OF PROGRAM EVENTS

The major program activities with supporting rationale are presented in chronological order. The Hecla program progressed through the following phases: entry, orientation, and diagnosis; designing the plan of action; implementing the action plan; consolidating and expanding the program accomplishments; and transferring the conduct of the program to company members. These phases and the actions taken to implement them are discussed in the following sections.

Entry, Orientation, and Diagnosis—1979

July 1979.—Hecla agreed to participate in the demonstration project, a memorandum of understanding was signed by the company and the consultants, and the program officially began.

August-December 1979.—The consultants conducted over 400 interviews with more than 60 salaried employees to learn about the company, the industry, mine safety, and mine productivity. These interviews provided an orientation for the consultants and a diagnosis of the organization's dynamics.

November 1979.—The president asked the consultant to design a new performance appraisal system for all salaried employees. The consultant agreed to do so. Development of the new system allowed the consultants to demonstrate their usefulness to the company and show the employees how OD consultants work. First, the goals and guidelines for the new system were solicited from the senior executives. Next, actual performance dimensions and performance standards were obtained from three representative groups of employees, who would be rated on the new forms. Suggestions for improving the appraisal system itself were also solicited. The consultants then drafted three new appraisal forms, one for managers, one for professional-technical employees, and one for clerical employees, which were submitted to the senior management team for its reactions and approval and to the representative groups for their reactions. Everyone liked the new forms and the new system that they had helped to create. This was an early success for the OD program that had high visibility and widespread approval.

Proposal and Plan of Action—1980

January 1980.—A report summarizing the organizational diagnosis and proposing several alternative ways to proceed was given to the president and senior management team.

February 1980.—A meeting was held with the president and senior executives to decide on the strategy and implementation of the OD project. The proposal was reviewed, the strengths and weaknesses of the company were discussed, and a plan of action was decided. The following decisions were made: team building-problem solving meetings would be the principal intervention used, the program would focus on the operations (production) function in the company, the program would start at the top of the organization and would eventually involve the hourly employees, the target mine would be the Lucky Friday Mine, and mine safety would be addressed by teams at all levels of the organization.

April 1980.—The new performance appraisal system was installed. All raters were given a one-half day training session conducted by the consultants on how to use the new system and how to conduct performance appraisals. The training was well received; it yielded another early success for the program.

Implementing the Action Plan—1980-82

June 1980.—The first team building meeting with the president and senior management team was held. This launched team building-problem solving meetings in the company. The procedure for team building meetings was simple and straightforward: prior to the first meeting everyone was interviewed and asked to identify the strengths and weaknesses of the organization and the team. The interview results were reported to the group at the first meeting and the team was asked to prioritize the problem areas in order of importance. The prioritized list was then worked through, each problem was examined, and action plans were developed and implemented to solve the problems.

August 1980.—The first team building meeting with the vice president of operations and the operations team was held. On this team were the vice president, three mine managers, the project engineer for the Silver Shaft (a new shaft at the Lucky Friday), and the assistant personnel director, who had corporate responsibility for mine safety.

October 1980.—Team building with the Lucky Friday mine manager and mine top management team was begun. This team consisted of the mine manager, the mine superintendent, three production foremen, and support personnel from maintenance, safety, geology, engineering, accounting, and warehousing.

The guiding strategy for 1981 was to continue everything already begun and concentrate on the Lucky Friday Mine.

February 1981.—The first team building meeting with the Lucky Friday production team was held. This team included the mine manager, mine superintendent, mine foremen, shift bosses, the maintenance foreman, and the safety forman. Policies were developed and implemented that caused long-standing problems to disappear; agreements on goals, procedures, and mutual expectations were reached that caused better coordination and cooperation. Another important benefit was that the shift bosses came to realize that the company was interested in them, their problems, and their ideas.

March 1981.—A 9-week strike occurred at the Lucky Friday Mine. The strike lasted from March 21 to May 23.

April 1981.—Annual goal setting meetings with the vice president of exploration and the exploration department were begun.

August 1981.—Team building meetings with four Lucky Friday production crews and their shift bosses were begun. Six 45-min meetings were held in 1981. Prior to to the meetings, the consultants explained the program to the top union officials at the mine, the president, secretary-treasurer, and safety committeeman. They were very supportive of the program and offered to explain and endorse it to the crews. They particularly liked the idea of initiating a constructive dialogue in which management would hear the views of the hourly employees.

September 1981.—Intergroup team building meetings were held with opposite shift crews. These meetings were designed to increase communication, coordination, and cooperation between crews that worked the same level of the mine and same stopes (working places), but worked on different shifts.

November 1981.—Team building meetings with the Lucky Friday maintenance crew and supervisors were begun.

May 1982.—The Bureau of Mines demonstration project was completed. A final report to the Bureau evaluating the Hecla project concluded that the program probably improved mine safety but had no discernible effect on mine productivity.

May 1982.—The president hired the consultant to continue the OD program and extend it to the rest of the company.

Consolidating Achievements, Expanding the Program, and Transferring the Conduct of the Program to Company Members—1982-85

These phases continued the implementation of the action plan, but added three new emphases—making the team building meetings a permanent fixture in the company, expanding the team building meetings to include other units, and training company members to conduct the program. Team building meetings have become a fact of life at Hecla: the senior management team holds annual 2-day meetings, the operations team holds two 1½-day meetings per year, and the Lucky Friday Mine top management team and mine production team hold quarterly meetings. Meetings with the crews conducted by the consultant have not been held since early 1982, but problem solving meetings with the hourly work force conducted by Lucky Friday supervisors and managers are routinely held. Team building meetings have been expanded to include all the major functional units of the company.

June 1982.—Behavior modeling skills training was initiated for the Lucky Friday mine superintendent, mine foremen, and safety foreman. Behavior modeling is a training technique that teaches supervisors how to become more effective at handling interpersonal problem situations.

June 1982.—Mining operations at the Star Mine were discontinued for economic reasons.

November 1982.—Team building meetings, conducted jointly by the personnel director and the consultant, were begun at the Knob Hill gold mine in Republic,

WA. The teaching of OD consultant skills to the personnel director was accomplished using an apprenticeship approach, in which the personnel director was a coconsultant on the project.

May 1983.—A 2-day annual retreat for the president and senior management team was inaugurated to replace the previous team building meetings.

June 1983.—Team building meetings with the corporate secretaries were held. Discussions and decisions centered on secretarial policies and procedures.

September 1983.—A new mine manager was appointed at the Lucky Friday Mine. To orient him to the team building process and to get the process started on a sound footing, a new series of diagnostic interviews was conducted, the results of which formed the agenda for the next several meetings. These meetings were conducted jointly by the director of training and the consultant, using an apprenticeship approach.

February 1984.—Team building meetings with the technical services department (the corporate engineering department), conducted by the director of training and the consultant, were begun.

November 1984.—Team building meetings with the corporate administrative services group, conducted by the director of training and the consultant, were begun. Two vice presidents and their teams attended these meetings; together they constitute all the administrative support functions in the company—legal, accounting, data processing, payroll, etc.

January 1985.—A new program, team problem solving (TPS), was initiated by the director of training and consultant. TPS had two broad objectives: teaching team problem solving skills to line managers and developing additional team building facilitators in the company. The first group to get TPS was the Lucky Friday mine manager and mine top management team. Later the program included the shift bosses at the Lucky Friday, and it then was expanded to other company units. Seven midlevel managers were trained to become internal OD consultants, using a classroom teaching and apprenticeship format.

March 1985.—Team building meetings, conducted by the personnel manager and consultant, were begun with the mine manager and management team at the Escalante Mine near Cedar City, UT.

Summary

Organization development techniques such as coaching and counseling, goal setting, team building-problem solving, intergroup problem solving, and role clarification are now normal, routine modes of operation at Hecla Mining Co. Teams at all levels periodically meet to discuss two questions: How are we doing? How can we do better? Seeking answers to these two questions is the essence of team building-problem solving, and, in fact, OD. These meetings are usually conducted by the managers themselves or by the managers with assistance from an internal OD consultant.

The strategy, rationale, and activities of the Hecla program presented in this section show how the program was designed and implemented. Team building was an excellent vehicle for conducting the program. Institutionalizing team problem solving skills by training line managers and internal consultants ensured that the program would be continued.

RESULTS

This section examines the effects of the OD program using safety and productivity data from 1979 through June 3 1985. Did the program do any good? That is the question to be answered. Nine performance indicators were analyzed, one for mine safety and eight for mine productivity. Program effects were estimated by examining preprogram and postprogram measures at the Lucky Friday Mine (a before-and-after comparison), and by examining results at the experimental mine and comparison mine. These analyses permit inferences to be made about possible program effects.

The years 1979 and 1980 were treated as the preprogram years; 1981 and following were the postprogram years. The OD program at the Lucky Friday Mine actually began in mid-1981, but using the base period of 1979 and 1980 to approximate the before condition is satisfactory for this paper. Data were collected at the Lucky Friday Mine through June 1985.

In addition, t-tests were calculated on Lucky Friday data to determine the statistical significance of differences before and after the OD program. The t-tests were generated using quarterly averages. There were nine preprogram quarters—from January 1979 through the first quarter of 1981; there were 16 postprogram quarters—from the third quarter of 1981 through the second quarter of 1985. Data from the second quarter of 1981, during which a 9-week strike occurred, were not used in the t-test analyses.

It is important to specify the date of the onset of the OD program. Team building meetings with the mine manager and mine top management team were initiated in October 1980. Team building meetings with the mine manager and mine production team began in February 1981. The strike occurred from March 21 to May 23, 1981. Team building meetings with the crews occurred in August, September, and October of 1981. It seems reasonable to fix the beginning of the program as the end of the second quarter of 1981. At that time several meetings had been held with the mine top management team and the mine production team, the strike was over, and operations at the mine were returning to normal. The preprogram period is up to the strike; the postprogram period is after the strike, beginning in July 1981.

DESCRIPTION OF MEASURES

Data to evaluate the program were obtained from company records. The company routinely monitors safety and productivity by means of standard indicators used throughout the industry. The nine indicators used in the present analyses are described in the following sections.

Lost-Time Injury Incidence Rate

The standard measure of mine safety is the lost-time injury incidence rate obtained by the formula, lost-time injuries × 200,000 /employee-hours.

Worker Hours of Exposure

Data for this measure were taken from Hecla records and Mine Safety and Health Aministration (MSHA) records.

Tons Per Day

This is the number of tons of ore removed from the mine in a single working day. Tons per day is an absolute number, not an input-output ratio. It will vary both as a function of productivity and as a function of managerial decisions. For example, during the period under investigation, management deliberately increased the output of the mine from 750 st/d to 1,000 st/d.

Total Ounces of Silver

This is the number of ounces of silver produced in a given time period. Silver is the main salable product of the Lucky Friday Mine. Total ounces of silver is the number of units of product available to be sold. This is an absolute number, not an input-output ratio.

Tons Per Worker Shift-Stoping

This is the number of tons of ore removed from the mine in a working day divided by the number of shifts worked by the stope miners who produced the ore. It is a standard productivity measure in the industry, and is the purest measure of productivity of the stope miners, the people who break the rock.

Tons Per Worker Shift-All Labor

This is the number of tons of ore removed from the mine in a working day divided by the total number of worker shifts worked at the mine. It includes the shifts of stope miners and all support personnel, both underground and on the surface. This measure will vary both as a function of changes in productivity and as a result of management's effectiveness in utilizing mine personnel. For example, if the number of tons of ore increases, but the number of all labor worker shifts increases even more, the net result is a decrease in this indicator.

Grade of Silver, or Ounces per Ton

This is the number of ounces of silver per ton of ore removed from the mine. This standard measure of production quality is a function of several variables: good mining practices by the stope miners, geological conditions, and managerial decisions. The miners can influence grade by carefully mining on the vein and not diluting the ore with waste rock. Geological conditions dictate the amount of silver available to be mined. Managerial decisions influence grade primarily through the amount of development work going on in the mine—if there is extensive development work, more waste rock will be mixed with the ore causing grade to decline.

Ounces of Silver Per Worker Shift—All Labor

This is the total amount of silver produced by the total worker shifts required to obtain it. This measure shows the output of salable product per unit of labor required to produce it.

Cost Per Ton

This is the production costs in dollars for each ton of ore removed from the mine, a standard cost meaure in mining. Costs are proprietary information, so the present analyses use percentages in the presentation of results.

Cost Per Ounce

This is the production costs in dollars for each ounce of silver produced, a standard indicator of cost per unit of salable product. The present analyses use percentages in the presentation of results.

BEFORE-AND-AFTER RESULTS AT THE LUCKY FRIDAY MINE

The results for each performance measure at the Lucky Friday Mine are presented and discussed in this section. For comparison purposes, the years 1979 and 1980 are treated as before and the years 1981 though June 1985 are treated as after in the analyses. Table 1 shows annual averages for the safety and production measures. Table 2 presents the same data transformed into percentage changes from the base period 1979-80, and in addition shows cost information in percentage changes from the base period.

Lost-Time Injuries

The data in tables 1 and 2 show a 44.1 pct decrease in lost-time injuries in 1981, the year the OD program was initiated. It is reasonable to assume that some of this improvement was due to the program. Thus the primary question the Bureau wanted answered—Can OD techniques improve mine safety?—is answered: Yes, they can.

In addition, the gains in mine safety were sustained over time. The injury rate increased somewhat in 1982, decreased again in 1983, and increased in 1984. But the rates remained below the base period, averaging a 38.2 pct decrease for the 4-yr period 1981 through 1984. In 1985, there was a dramatic drop in injuries—a 78.7 pct improvement over the base period. The employees at the Lucky

Table 1.—Annual averages of safety and production measures at the Lucky Friday Mine, 1979 through June 1985

Measure	1979	1980	1981	1982	1983	1984	1985
Safety: Lost-time injury incidence rate	22.92	23.04	12.85	15.62	13.27	15.11	4.9
Production:							
Ore .... st/d	704	737	716	837	1,017	1,017	1,100
Silver ..... 10^6 oz	2.884	3.118	2.253	3.858	5.145	4.786	5.004
Productivity, st/worker shift:							
Stoping	11.23	11.46	11.19	10.84	13.39	15.55	17.51
All labor	2.98	2.90	2.64	3.16	3.40	3.24	3.90
Grade .... oz/st	16.67	16.78	15.14	18.30	20.42	19.03	18.28
Productivity oz/worker shift	49.44	48.78	40.53	58.63	69.27	61.64	72.28

Table 2.—Comparison of safety, production, and cost measures at the Lucky Friday Mine, 1981 through June 1985, percent

[Base (1979-80) = 100 pct]

Measure	1981	1982	1983	1984	1985
Safety: Lost-time injury rate	55.9	67.9	57.7	65.7	21.3
Production:					
Short tons per day	99	116.2	141	141	152.7
Total ounces of silver	75.1	128.6	171.4	159.5	166.7
Short tons per worker shift:					
Stoping	98.6	95.5	118	137	154.3
All labor	89.7	107.5	115.6	110.2	132.6
Ounces per short ton	90.5	109.4	122.1	113.8	109.3
Ounces per worker shift, all labor	82.5	114.6	141	125.5	147
Cost:					
Dollars per short ton:					
Actual	143	111.2	106.3	131.9	123.2
Inflation adjusted	123	89.5	82.9	98.7	89.9
Dollars per ounce:					
Actual	154.4	100	87.4	116.6	108
Inflation adjusted	133.7	80.5	68	87.3	79

Friday Mine went 88 working days without a lost-time injury, which was an all-time record.

It appears that the results show two major discontinuities: the first occurred in 1981 and continued through 1984, and the second occurred in 1985. Both the 1981 results and the 1985 results mark significant departures from previous periods. A t-test showed that the lost-time injury incidence rate was significantly lower after the OD program: $t(23) = 2.60$, $p < 0.01$ for one-tailed test.

Tons Per Day

The data for tons per day show that the quantity of ore removed per day decreased 1 pct in 1981, then rose from 1982 through 1985. A gain of 16.2 pct was achieved in 1982, followed by gains of 41 pct in both 1983 and 1984, and 52.7 pct in 1985. These increases in total mine output were due to a combination of causal factors: management decisions to increase production, more employees on the payroll, and greater productivity. The amount of contribution of each of these factors (and the OD program) cannot be determined. What is clear is that production of ore was increased from approximately 700 st/d in 1979 to 1,100 st/d in 1985. A t-test for tons per day before and after the OD program showed the differences were significant: $t(23) = 5.44$, $p < 0.0005$ for a one-tailed test.

Total Ounces of Silver

This is an absolute number that depicts how much salable product is generated in a given time period. Total ounces produced depends on a number of factors such as managerial decisions to increase the tons of ore mined, mining more or less rich parts of the mine, and productivity of individuals. Total silver output decreased by 25 pct in 1981 compared to the base period, but increased substantially in the following year—up 28.6 pct in 1982, up 71.4 pct in 1983, up 59.5 pct in 1984, and up 66.7 pct in 1985. These are substantial increases compared to the preprogram levels. The differences in silver production before and after the OD program were statistically significant: $t(23) = 1.793$, $p < 0.05$ for a one-tailed test.

Tons Per Worker Shift—Stoping

The ore is produced by miners who work in stopes drilling, blasting, and mucking the ore. The best measure of stope miner productivity is the total number of tons of ore produced divided by the total number of worker shifts worked by stope miners. Annual averages for this measure are shown in table 1 and percentage changes are shown in table 2.

These data show a decrease of 1.4 pct in 1981 and a decrease of 4.5 pct in 1982, compared to the base years of 1979 and 1980. At that point, however, stope miner productivity started to increase: up 18 pct in 1983, up 37 pct in 1984, and up 54.3 pct in 1985. It is important to note that the impact of the OD program was not immediately reflected in improvements in stope miner productivity; rather, there was a delay of 1 yr before increases began to be seen. One explanation for this was that the company and the miners were engaged in a dispute over the administration of the contract system in late 1981 and 1982, with a slowdown staged by the miners in 1982. The issues were resolved in late 1982, and productivity started on a steady rise. A t-test for tons per worker shift—stoping before and after the OD program showed the differences were significant: $t(23) = 2.49$, $p < 0.025$ for a one-tailed test.

Tons Per Worker Shfit—All Labor

A good measure of overall mine efficiency is the total output of ore divided by the number of worker shifts worked by all persons at the mine. This measure reflects both the productivity of individual stope miners and the ability of management to utilize efficiently the total human resources at the mine.

Tons per worker shift—all labor was down 10.3 pct in 1981, up 7.5 pct in 1982, up 15.6 pct in 1983, up 10.2 pct in 1984, and up 32.6 pct in 1985 compared to the base period. Productivity started to improve in the third quarter of 1981; there was no delayed effect as seen for tons per worker shift—stoping. A t-test showed that the pre- and post-intervention differences were statistically significant: $t(23) = 2.96$, $p < 0.005$ for a one-tailed test.

Grade of Silver, or Ounces Per Ton

The grade of silver, measured in ounces of silver per ton of ore mined, is an indicator of production quality. Careful mining practices by the stope miners can increase the ounces per ton of ore. Additional factors contributing to grade are geological conditions and the amount of development activity.

Compared to the base period of 1979-80, grade decreased by 9.5 pct in 1981, but increased in the years following: up 9.4 pct in 1982, up 22.1 pct in 1983, up 13.8 pct in 1984, and up 9.3 pct in 1985. This is an important efficiency and effectiveness indicator, because keeping grade as high as possible means that fewer tons of waste rock have to be hoisted from the mine and processed through the mill. The increase in grade after the OD program was statistically significant: $t(23) = 3.68$, $p < 0.005$ for a one-tailed test.

Ounces of Silver Per Worker Shift—All Labor

A meaure that reflects both managerial effectiveness in utilization of human resources and individual productivity is the ratio showing the total ounces of silver produced divided by the total worker shifts worked to produce them, ounces per worker shift—all labor.

Compared to the base period, ounces per worker shift—all labor was down 17.5 pct in 1981, up 11.5 pct in 1982, up 41 pct in 1983, up 25.5 pct in 1984, and up 47 pct in 1985. This is a key efficiency measure, amount of salable product per unit of labor, and it shows substantial improvement from 1982 forward. The difference between preprogram and postprogram scores is statistically significant: $t(23) = 3.59$, $p < 0.0005$ for a one-tailed test.

Cost Per Ton and Cost Per Ounce

Two standard cost indicators are production costs measured by dollars per ton of ore mined and production costs measured by dollars per ounce of silver produced. Cost information is proprietary information for most mining companies, therefore the present analyses use percentage changes only. Analysis showed how well costs were being managed before and after the OD program. Both actual dollar costs and constant (inflation-adjusted) costs were examined. Table 2 shows annual cost per ton data by year.

Compared to the base period, actual production costs per ton of ore mined were up 43 pct in 1981, up 11.2 pct in 1982, up 6.3 pct in 1983, up 31.9 pct in 1984, and up 23.2 pct in 1985. The sharp increase in costs in 1981 was brought down in 1982 and 1983, but costs rose again in 1984 and 1985. A review of inflation-adjusted costs per ton shows that costs were up 23 pct in 1981, and then lower than the base period for the following 4-yr period: down 10.5 pct in 1982, down 17.1 pct in 1983, down 1.3 pct in 1984, and down 10.1 pct in 1985. These data show that costs were being controlled quite well in the postprogram period.

Cost per ounce reflects the costs involved in producing a unit of salable product. As shown in table 2, the cost per ounce in actual dollars rose 55.4 pct in 1981, then returned to the level of the base period in 1982. In 1983 costs showed a decrease of 16.6 pct but then were up 16.6 pct in 1984 and up 8 pct in 1985. In constant dollars, cost per ounce was up 33.7 pct in 1981, but down 19.5 pct in 1982, down 32 pct in 1983, down 12.7 pct in 1984, and down 21 pct in 1985. These figures show that management was doing a good job controlling costs except in the year 1981, the year of the strike and its settlement.

Summary and a Caveat

The data presented show a great deal of variability, but the trends are positive on all measures at the Lucky Friday Mine from pre- to post-intervention. Comparing the first 6 months of 1985 to the base period of 1979 and 1980 yields the following results:

Lost-time injury incidence rate—down 78.7 pct.
Total tons of ore produced per day—up 54.7 pct.
Tons per worker shift—stoping—up 54.8 pct.
Tons per worker shift—all labor—up 33 pct.
Total ounces of silver—up 72.1 pct.
Grade of silver (ounces per ton)—up 10.4 pct.
Ounces per worker shift—all labor—up 47 pct.
Cost per ton—actual dollars—up 23.2 pct.
Cost per ton—inflation-adjusted dollars—down 10.1 pct.
Cost per ounce—actual dollars—up 8 pct.
Cost per ounce—inflation adjusted dollars—down 21 pct.

There is significant improvement on all indicators—safety, quantity of production, quality of production, and costs. The year 1981 marked a turning point at the Lucky Friday. A 9-week strike occurred in March, April, and May; the OD program began in earnest in mid-1981. Lost-time injuries decreased dramatically in 1981 and have remained below preprogram levels ever since. Productivity measures reached their lowest point in 1981 and have risen substantially since then. All t-test comparisons showed that the differences between preprogram and post-program scores were significant. Clearly the mine is functioning better now than it was in 1979 and 1980.

But a caveat is appropriate here: it would be wrong to attribute all or even most of these positive changes to the OD program—so many different events were occurring over such a long period of time that precise identification of the causal factors can not be made. It is reasonable to conclude that the OD program had a positive impact on safety and productivity at the Lucky Friday Mine; but it is also reasonable to conclude that a number of non-program-related factors did too. Some of these other possible causes are discussed in the "Discussion and Conclusions" section.

COMPARISONS BETWEEN THE EXPERIMENTAL AND CONTROL MINES

The Lucky Friday Mine received the treatment as the experimental mine, while the Star Mine received no treatment as a comparison mine. Unfortunately the Star Mine was closed in June 1982, resulting in the loss of the comparison mine for long-term comparisons. Short-term analyses were possible, however, and they are reported in this section.

Two major evaluation problems resulted from the loss of the control mine. The first problem was the loss of the ability to make long-term comparisons between the two mines. The Lucky Friday analyses in the previous section showed that the data were highly variable, changes showed up at different times, and new trends were identified only after several years of observations. Although the data from the Star Mine showed gains, it is not possible to know whether these reflected permanent trends.

The second problem was that the Star data were distorted by the shutdown dynamics. Many people in Hecla were doing their best to keep the Star from closing. The employees at the mine worked harder and smarter in order to save their jobs. Managers and engineers looked for ways to make the mine more profitable. Mining in less profitable stopes (working places) was discontinued; more profitable stopes were double shifted, that is, were mined on both day shift and swing shift. Twenty percent of the work force was laid off on January 1, 1982. Persons with greater seniority and experience were retained after the layoff. Finally, 5,000 st of previously broken ore that was

stored in the mine was removed in the last months of operation. The point is that the shutdown dynamics created distortions in the performance measures and confounded the true changes that occurred with the changes because of the mine closure procedures. With these caveats and complications in mind, the comparative data between the experimental and comparison mines are examined. Comparisons were made on four indicators: lost-time injuries, tons per worker shift—stoping, tons per worker shift—all labor, and cost per ton. Analyses used data up to June 1982 at the Star Mine.

Lost-time injury incidence rates at the Lucky Friday and Star Mines (table 3) show the annual lost-time injury incidence rates and percentage changes at the Lucky Friday and Star Mines compared to the base years of 1979 and 1980. The Star Mine injury rates were lower than those at the Lucky Friday in 1979 and 1980. In 1981, the injury rate at the Lucky Friday decreased by 44 pct compared to a decrease of 8 pct at the Star. This may be evidence that the OD program had a positive influence on safety at the Lucky Friday, since there was a large rate decrease at the experimental mine and a small rate decrease at the control mine. In 1982, however, the injury rate was down 32 pct at the Lucky Friday and down 37 pct at the Star, compared to the base period. The decrease at the Lucky Friday was expected but the sizable decrease at the Star was not. The causes of the decrease in injury rates at the Star Mine are not known. It is also unclear whether the decrease signified a new trend for injuries at the mine.

TONS PER WORKER SHIFT—STOPING

Annual averages for tons per worker shift—stoping at the two mines are shown in table 3. Compared to productivity at the Lucky Friday, productivity at the Star Mine was higher during the base period and increased by 13.4 pct in 1981 and by 22 pct in 1982. Productivity at the Lucky Friday decreased in both these years compared to the base period. These gains at the Star Mine were substantial. Unfortunately, the shutdown dynamics made it impossible to determine the true significance of these positive results.

TONS PER WORKER SHIFT—ALL LABOR AT THE LUCKY FRIDAY AND STAR MINES

Table 3 shows annual averages for tons per worker shift—all labor at the two mines. This measure reflects both productivity and management's ability to utilize the mine workforce in an efficient manner. Again productivity at the Star Mine was higher than that at the Lucky Friday during the base period. Productivity increased at the Star by 8.8 pct in 1981 and 14.7 pct in 1982, compared to a decrease of 10.3 pct in 1981 and an increase of 7.5 pct in 1982 at the Lucky Friday. These gains at the Star Mine are impressive, but the causes of the improvements are unknown.

Table 3.—Annual performance averages at the Star Mine and Lucky Friday Mine for safety, production, and costs

(Comparison of 1981 and 1982 with 1979-80 base)

Measure	1979	1980	1981	1982[1]	Change, pct	
					1981	1982
Safety, lost-time injury incident rate:						
Star	15.2	15.2	14.0	9.6	92	63
Lucky Friday	22.9	23.0	12.85	15.6	55.9	67.9
Production, st/worker shift:						
Stoping:						
Star	16.7	15.4	18.2	19.6	113.4	122
Lucky Friday	11.23	11.46	11.19	10.84	98.6	95.5
All labor:						
Star	3.5	3.3	3.7	3.9	108.8	114.7
Lucky Friday	2.98	2.90	2.64	3.16	89.7	107.5
Cost, dollars per short ton:						
Actual:						
Star	W	W	W	W	107.7	105.1
Lucky Friday	W	W	W	W	143	111.2
Inflation adjusted:						
Star	W	W	W	W	92.4	84.4
Lucky Friday	W	W	W	W	123	89.5

W Withheld [1]Star Mine data are from January to June only.

COST PER TON AT THE LUCKY FRIDAY AND STAR MINES

Table 3 shows cost figures in percentages at the two mines compared to the base period of 1979 and 1980. Both actual dollar costs and inflation-adjusted or constant dollar costs are shown. The Star Mine showed actual cost increases of 7.7 pct in 1981 and 5.1 pct in 1982, but showed decreases of 7.6 pct in 1981 and 15.6 pct in 1982 in constant dollars. Cost per ton at the Lucky Friday Mine jumped 43 pct in actual dollars and 23 pct in constant dollars in 1981, the year of the strike and its settlement, and were up 11.2 pct in actual dollars and down 10.5 pct in constant dollars in 1982. Again there is evidence of significant improvement at the Star Mine during 1981 and 1982, the causes of which can not be precisely identified.

SUMMARY

All the indicators showed improvement at the Star Mine, the comparison mine, in 1981 and up to the mine's closure in June 1982. Whether the trends were permanent and what the causes of the gains were can not be known from these data, because the impact of the shutdown dynamics could not be isolated and specified. The gains at the Star Mine did not achieve the magnitude of the gains at the Lucky Friday Mine found in 1985, however.

DISCUSSION AND CONCLUSIONS

The OD program has been described and the results reported. In this section, several conclusions are advanced, concurrent events that may have caused the results are examined, ingredients for success are identified, and implications of this research for the mining industry are proposed. (Although this research was conducted in a silver mining company, it is probable that the results apply equally well to the entire mining industry, both metal-nonmetal and coal.)

CONCLUSIONS

Important positive changes occurred at the Lucky Friday Mine and Hecla Mining Co. since 1979 on almost every performance indicator. Hecla is the premier silver mining company in the United States. Hecla's top management team is very highly regarded; for 5 of the past 6 yr, The Wall Street Transcript has named Mr. Griffith the top silver company chief executive in the Nation. Safety and productivity have improved dramatically at the Lucky Friday since 1981.

It is reasonable to believe that the OD program was a positive force at Hecla. It was not the only positive force or even the most important positive force, but it probably contributed to better organizational effectiveness, especially at the Lucky Friday Mine. The first conclusion is that OD techniques can improve mine safety and productivity in hard-rock mining. The data strongly support such a conclusion.

A second conclusion is that the OD approach is acceptable to mining company executives and employees. The essence of the OD approach is that an outsider, a behavioral science consultant, collaborates with the organization's members, helping them to concentrate their expertise on solving their most important problems. The consultant provides a method; the organization members provide the effort, energy, and expertise. The method must be compatible with common sense, good management practices, and the culture of the organization. OD techniques, especially team building, are natural, nonthreatening, effective activities that facilitate problem solving. The OD approach uses a rational, data-based foundation, encourages participation and involvement by the key persons, focuses on task accomplishment, and deals with real issues not hypothetical cases. This combination appealed to Hecla's employees; it would likely appeal to executives and employees of other mining companies.

A third conclusion, evident in the results at the Lucky Friday Mine, is that mine safety and productivity can be improved simultaneously—they are not mutally exclusive outcomes. On reflection this conclusion should not be surprising: good safety practices and high productivity both result from good management practices and good employee attitudes. Any program that improves managerial skills and employee involvement should improve safety and productivity together.

Fourth, team building-problem solving meetings are a powerful technique for increasing organizational effectiveness. This is true for several reasons. Team building meetings address and solve high-priority problems facing the team; this in itself causes better functioning. In addition, team building causes a shift toward a more problem- and task-oriented focus. This shift serves to energize and empower people. Individuals and teams become more competent and able to face other demands placed upon them at work. Finally, team building is not very different from what effective leaders and teams do naturally—take a systematic look at how they are getting the job done in order to find ways to do it better.

CONCURRENT EVENTS AND RIVAL EXPLANATIONS

Attributing causality for the positive results achieved at the Lucky Friday Mine is difficult. The OD program was probably one positive factor in producing the improvements. But there were other factors and events that (1) produced positive results and (2) can be considered rival explanations as the causes producing the changes. Because this was a global intervention extending over 6 yr, many rival explanatory events were happening concurrently with the OD program. Several rival causal factors are discussed here.

Important management changes occurred coincident with the OD program. William Griffith was appointed president and chief executive officer of the company in May 1979. He has exerted strong influence on every aspect of the company, including promoting mine safety and productivity. A new vice president of operations was also appointed in May 1979; he was experienced and knowledgeable and emphasized safety and productivity. A new mine manager was appointed at the Lucky Friday in 1980, and he served in that position until September 1983. The mine was turned around during his tenure as mine manager. His leadership and the new policies and procedures initiated by him were possible causes of the improvements at the mine. The mine manager who took over in 1983 showed strong, innovative leadership. It is likely that all these management changes were significant, positive forces contributing to the improvements that were achieved.

Several mine policy changes probably played causal roles in increased performance. In 1982, a minable width policy was introduced that specified how wide on the vein stope miners could mine and still be paid for the broken rock. The intent and effect of this policy was to reduce the amount of waste rock being mined and to have the miners only extract ore-bearing rock. This policy probably affected grade, total ounces of silver, and ounces per worker shift—all in a positive manner. In 1983, a new contract incentive system was tested and then implemented minewide. This incentive system improved both the quantity and quality of ore mined, was perceived as more fair than the previous system, and increased the amount of money the stope miners could make. This new system probably increased productivity. In 1985, the mine manager negotiated individual performance contracts with all the shift bosses. These contracts amounted to goal setting for each first-line supervisor for costs, safety, and production quantity and quality. Goal setting is a proven way to increase performance.

The year 1982 saw the closure of several large mines in the Coeur d'Alene district; metal prices were very low; many miners were looking for work. These conditions may have influenced performance at the Lucky Friday and Star Mines.

These concurrent events can be considered rival explanations for the improvements at the Lucky Friday Mine instead of the OD program. The nature of the data is such that the effects of these specific events can not be isolated. It is likely that all these factors (and more) were related to the results obtained.

INGREDIENTS FOR SUCCESS IN THE PROGRAM

The OD program was successful in two ways: it was well received by the organization, running its planned course with no disruptions; and it produced good results. The second outcome was made possible by the first. An assessment of the ingredients for success reveals the conditions under which OD programs might be successfully implemented in other hard-rock mining companies.

One of the most important factors for success was the support given by Hecla's chief executive. Mr. Griffith insisted that the program be well conducted, be good for the organization, and be seen as useful by company members. As positive reports about the program accumulated, Mr. Griffith used the force of his position and personality to promote the program. When he started team building with himself and the senior management team, that sent a clear signal to the rest of the organization that the consultant and the program were being taken seriously. He showed his strong support again when the company assumed sponsorship of the program in June 1982, and it was at his direction that the program was institutionalized.

Another success factor was the support given to the program by the original Lucky Friday mine manager. New to the job, he welcomed the program as a means of accomplishing his objectives. Team building proved to be an excellent mechanism for ensuring communication, cooperation, and coordination with the managerial group at the mine. Mine policies and procedures were analyzed in team building meetings and reaffirmed, modified, or created as needed. As progress was made on chronic problems, the mine manager and the entire managerial team became champions of the program. The mine manager's successor in 1983 was equally supportive of the OD effort; he expanded the program substantially, spearheaded the institutionalization process, and initiated many managerial improvements.

The overall program strategy was a good one. Team building-problem solving meetings proved to be a good mechanism for bringing about change at Hecla. Starting at the top of the organization and working down the hierarchy was a sound approach. Focusing on real problems and opportunities, and translating words into action steps made team building meetings vital, rewarding, and fun.

Several early successes helped legitimatize and energize the program for company members. The new performance appraisal system demonstrated the OD approach and resulted in an immediate useful product. The diagnostic-orientation interviews created high visibility and showed that the consultants were genuinely interested in helping the organization. Quick solutions to several long-standing problems at the Lucky Friday Mine created a sense of momentum and accomplishment for the mine management team. Early successes served as great testimonials for the OD program.

Important developments in the past 2 yr that helped the success of the program included training company members to be internal OD consultants, and training line managers in team problem solving skills. Starting with the personnel manager and the director of training, the internal consultant group has been expanded to include a total of nine people. The facilitator cadre at Hecla is a potent force for success and for keeping the program viable.

IMPLICATIONS FOR THE MINING INDUSTRY

OD is a process for improving managerial practices and organizational dynamics toward the goal of improving organizational effectiveness. The Hecla project showed that OD can work in mining companies and that OD can improve mine safety and productivity.

This demonstration project clarified something most people already know but often forget: mine safety and productivity are as much human and social results as they are engineering and technology results. Remove the personnel-created barriers to safety and productivity and positive, permanent improvements will be forthcoming. OD programs systematically analyze and overcome barriers to effectiveness, efficiency, and satisfaction in organizations. The implications for the mining industry are that programs focusing on the human side of performance are available; these programs can produce bottom-line benefits, and mining executives can evaluate these programs to see if any are appropriate for their companies.

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STRUCTURED MANAGEMENT TRAINING IN UNDERGROUND MINING—FIVE YEARS LATER

By Fred E. Fiedler[1]

ABSTRACT

A demonstration project in an underground trona mine showed that structured leadership training, consisting of leader match and behavior modeling, led to increased mine safety and productivity, with nearly undiminished effects over a 5-yr period. The training was highly cost effective and has considerable promise for widespread implementation.

INTRODUCTION

A principal mission of the Bureau of Mines is the development of a safer and more productive work environment. But despite extensive Federal and State regulations, mandated safety training and improvements in safety devices and mining techniques, underground mining is likely to remain one of the more hazardous occupations. In its continuing effort to improve mine safety, the Bureau conducted a 3-yr demonstration project, 1979 to 1982 (*1*).[2] The project was based on the rationale that mine safety is a management responsibility and that the adherence to safety rules and regulations depends in large part on the attitude of supervisors and their ability and willingness enforce safe work practices.

Although management training absorbs millions of dollars each year, few, if any, studies have inquired what kind of training has relatively lasting effects. Most training evaluations are content with determining whether the trainees had found the instruction interesting and had learned from it. A followup over a 5-yr period is unique in the training literature. This paper briefly describes a method of management training, and data on the mine's safety and productivity during the subsequent 5-yr period after training.

THE DEMONSTRATION PROJECT

The Texasgulf trona mine in Granger, WY, was the site of the demonstration program. It is one of four trona (or soda ash) mines located within a 10-mile radius about 50 miles from Rock Springs, WY. This area produces nearly all the trona ore in the United States.

The four mines in the Granger area are quite comparable. They operate in the same geological formation, and generally use similar technology; their workforce is drawn from the same labor pool, and many miners had worked in several of these mines over the years. Needless to say, all mines routinely conduct the individual safety training mandated by the Mine Safety and Health Administration (MSHA).

The evaluation of the training program was based primarily on records the mining companies are required to furnish MSHA and the Wyoming State Inspector of Mines on the mine's ore production and on accidents and injuries. Data were originally obtained for the period 1978 to 1981, which included the period immediately prior to, as well as the 2 yr following the management training intervention. The present study reports additional data obtained for 1982 to 1985.

At the time the study began, the Texasgulf Mine had been in operation for 3 yr and employed about 500 employees, with about half of its employees in its underground mining operation. The others were employed in administration and a crushing mill. Although its productivity was relatively similar to other mines in the area, the mine's safety record was poor and the number of violations reported by MSHA inspectors was quite high (*2*).

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[2]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

Individual safety training in the proper use of equipment and procedures is an essential and indispensable part of the total safety program. However, it is the responsibility of management, and especially the first-line supervisor, to monitor and enforce compliance with safety procedures, rules and regulations. The demonstration project also recognized, however, that a safety program has little chance for success or long-term survival if it interferes with mine operations, and that its acceptance will be assured to the extent to that it contributes to mine productivity.

The training selected consisted of two well-established and tested programs that complement each other, namely leader match (*3-4*) and supervisory skills training, behavior modeling, adapted from Goldstein and Sorcher (*5*).

Leader match takes about 8 h to administer (*3-4*). It is based on Fiedler's contingency theory, which states that the effectiveness of a leader or a group depends on two interacting variables. These are (1) the leader's primary motivation either to accomplish the task or to establish and maintain close interpersonal relations with members of the group (*6*); and (2) the leader's power, influence, and control over group process (situational control).

The training consists of three parts. The supervisor identifies his or her leadership style by means of a short scale, and is then taught how to interpret the score. Second, the supervisor learns to diagnose the leadership situation by learning to recognize the signs of relatively good or poor leader-member relations, high or low task structure and strong or weak position power. The third part of the training teaches the leader that his or her leadership style will be most effective in certain types of leadership situations, and how to match the leadership situation to the specific type of personality brought to the task.

In contrast to other leadership training methods that attempt to change the leaders personality or behavior, leader match shows the manager how to modify situational control so that it matches his or her personality and style of interacting with subordinates (rather than trying to teach the manager how to change behavior or personality). This method has been successfully tested in a number of field experiments (*7-8*).

Supervisory skills training was developed at the General Electric Co. The version used consisted of eight short videotaped vignettes to illustrate how effective mine supervisors handle such common problems as dealing with an irate employee, disciplining a subordinate, or reinforcing safe behavior. Groups of 8 to 12 supervisors view the vignettes, discuss the learning points, and role play the situations. The training emphasizes common leadership problems faced by the supervisor, and focuses on concrete supervisory skills in handling employee problems. The training, adapted from Goldstein and Sorcher (*5*), requires about 16 h. Several studies have validated this method (*8-9*).

TWO-YEAR ASSESSMENT OF THE PROGRAM'S EFFECTIVENESS

The first evaluation of the training program was conducted in 1981 (*2*). It indicated that both productivity and safety had improved substantially during the 2 yr after training. The productivity of the demonstration mine was 0.06 pct above the industry average when the study began, but 7.0 pct above the industry average in 1982, 2 yr after training. Likewise, the number of accidents and injuries was 226 pct above the industry average before the training but dropped to less than 2 pct above the industry average 2 yr after the training intervention. In addition, citations by MSHA for safety violations had decreased by almost 90 pct over the level of the years immediately preceding the training. At the same time, an employee job survey conducted by an independent company, showed that satisfaction with the company's safety efforts had improved by 24 pct in the underground mining operation.

THE FIVE-YEAR FOLLOWUP STUDY

It is important to note that the years 1980 to 1984 were a very turbulent time for the demonstration mine. Among these events were, successively, a proposed expansion of the mine, a plane accident that caused a major loss of senior company officials, and the acquisition of the company by a French conglomerate. All of these events caused uncertainty and anxiety. In addition, the trona mining industry was severely depressed by the strong economic downturn that especially affected its major customers, the automobile and construction industries.

Trona cannot be stored for a long period of time, and a declining demand for the product necessitated reductions in trona mining operations. In order to retain its skilled workforce, Texasgulf assigned many of the miners to development and maintenance activities. This meant, however, that the ratio of tons per employee-hours reportable to MSHA no longer reflected mine productivity; an unusually high proportion of miners were now assigned to nonproduction tasks. The demonstration mine therefore measured its own productivity on the basis of the number of miners who were actually assigned to ore extraction. Unfortunately, it was not possible to obtain a similar measure of productivity from the comparison mines.

RESULTS BASED ON OBJECTIVE DATA

The 5-yr followup study was based, insofar as possible, on official records using data similar or identical to those obtained in the 1981 study. These again included tons of ore per employee-hour, and number and severity of accidents per 200,000 employee-hours (as determined by the number of employee days lost). The number of MSHA citations for safety violations was also obtained. According to comments by mine managers and MSHA safety inspectors, a low number of citations reflects safe working conditions and a high level of support for safety regulations by

management. In addition, data were obtained from the demonstration mine which, as already mentioned, calculated tonnage per scheduled production hour to reflect the reassignment of skilled employees to development and maintenance work.

Figure 1 shows worker productivity in tonnage per employee for the Texasgulf Mine and the industry. In 6 of the 7 yr, the Texasgulf Mine showed a better production record than the average of other trona mines in the industry. This is especially noteworthy in the years immediately after the management training intervention. The sole exception was the year 1983, in which the Texasgulf Mine production fell substantially below the industry average.

As already mentioned, the Texasgulf Mine diverted many of its skilled workers to nonproduction tasks in order to retain their services during the severe slump in trona demand. For this reason, the mine used tonnage of *scheduled* production per employee-hour. The data in figure 2 thus present a more accurate reflection of the mine's actual productivity. It can now be seen that productivity at the mineface increased throughout 1980, the period for which these data are available. The apparent decrease in productivity in 1983, therefore, should be seen as an artifact of measurement.

The demonstration mine also steadily reduced the number of safety violations during the past years. Although the number of citations issued to all of the mines in the study has generally decreased since 1979, the demonstration mine further improved its safety record over the comparison mines. Since the intervention, the demonstration mine reduced the number of citations issued by MSHA by more than 80 pct of the baseline year (fig. 3).

Furthermore, the reportable rate of accidents and injuries also decreased dramatically at the Texasgulf Mine, when compared to the industry average for the available years, and beyond that time for the years 1983 and 1984 (fig. 4). Finally, figure 5 shows the accident severity for the 1978-84 period. As can be seen, severity of accidents and injuries, measured by number of employee days lost because of accidents, steadily declined since 1979.

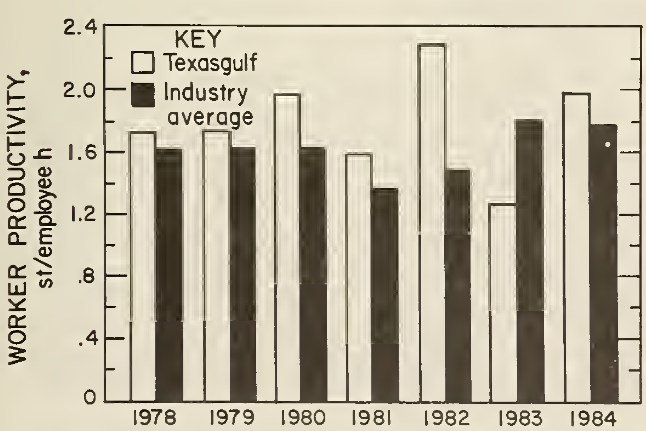

Figure 1.—Comparison of worker productivity between Texasgulf and trona industry average, 1978-84.

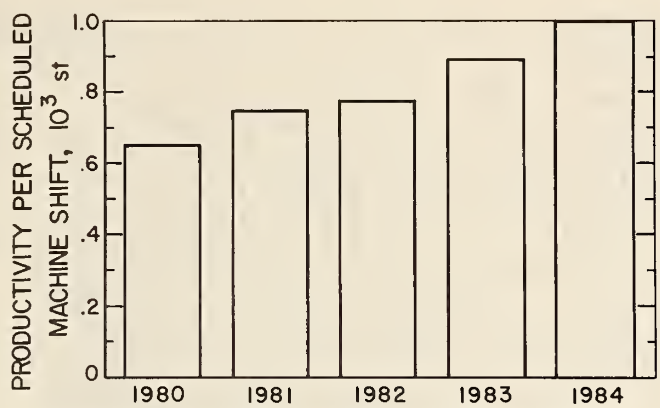

Figure 2.—Productivity at the mine face, 1980-84.

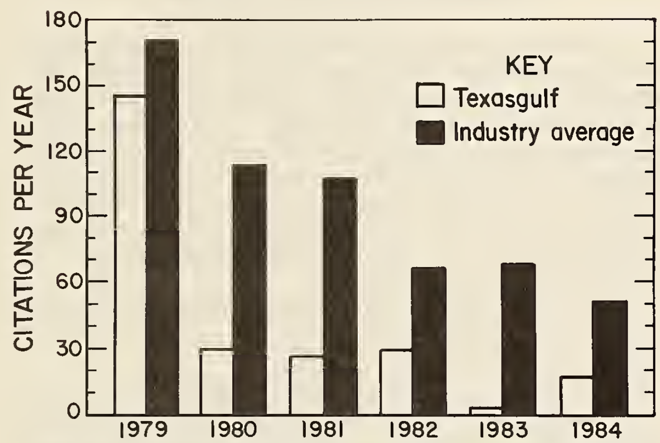

Figure 3.—Comparison of Mine Safety and Health Administration citation between Texasgulf and trona industry average, 1979-84.

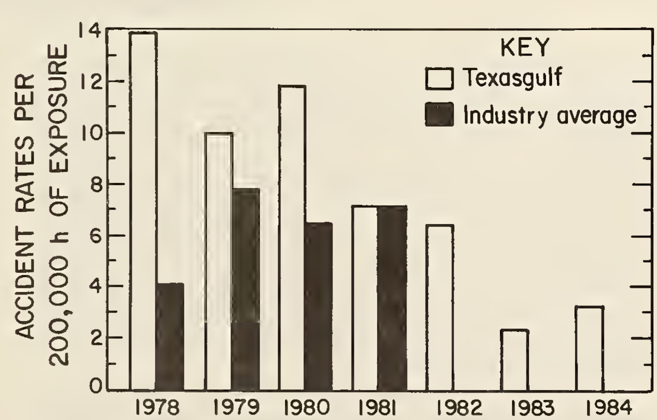

Figure 4.—Accident rates for the trona industry as reported by the Mine Safety and Health Administration (data on other trona mines not available at this time), 1978-84.

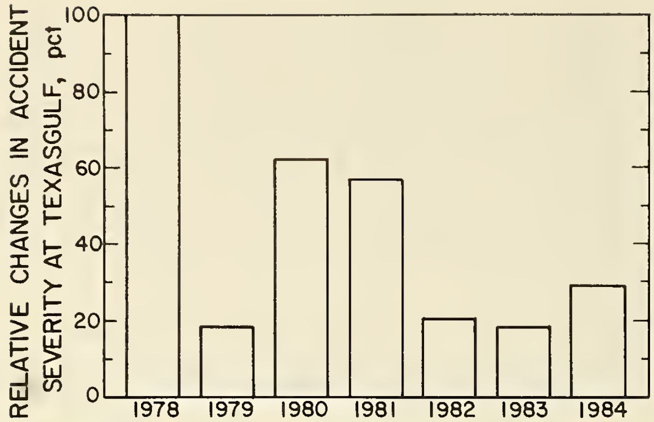

Figure 5.—Relative changes in accident severity at Texasgulf trona mine during the 1978-84 period.

QUALITATIVE EVALUATION

It would be difficult to interpret the findings without knowing about the other major events that might have affected productivity and safety in the organization in the 5-yr period subsequent to training. For this reason six mine managers, who could judge the effects of the training program in the light of the conditions at the mine since 1982, were interviewed. These interviews were made on a confidential basis by a senior investigator, who had intimate knowledge of the mine and the original project.

Those interviewed included

1. The mine manager, who had joined the management team after the end of the training intervention.
2. The mine production manager.
3. The surface production (mill) manager.
4. The director of employee relations, who had been the assistant director of employee relations during the original project.
5. The director of training and safety, who had come on site after the end of the training intervention.
6. One member of the training staff.

Only the mine production manager had been involved in the company's decision to participate in the original project. The others did not have a vested interest in the project's success or failure, and only one of the managers had been directly associated with our program. If anything, one might expect, therefore, that the interviewees would want to play down the effects of the training and to emphasize their own role in improving productivity and safety. Interviews dealt with three areas

1. Changes in policy or procedures that might have affected productivity and safety.
2. The validity and appropriateness of the various productivity and safety indexes.
3. Perceptions of the effects of the demonstration project training.

Although they saw the organization from different perspectives, all interviewees stated that the mine had made very few significant changes in either policy or procedures, and that operations in the mine had continued relatively unaltered since the time of the training. No major changes had taken place in the nonsalaried workforce nor had additional training (beyond MSHA requirements) been offered in leadership, supervision, or safety.

Four of the six managers had remained with the organization since the training intervention. They felt that the training had brought about significant changes in the way managers thought about their jobs, and about productivity and safety. They expressed the opinion that the training program was responsible in large part for the high level of productivity and safety, and they pointed to the current quality of supervision as one indication that training had beneficial effects. They also mentioned that supervisors and executives still occasionally used some of the terms they had learned in their training, indicating that they had found the concepts relevant to their everyday activities.

SUMMARY AND CONCLUSIONS

The demonstration program was a case study with comparison groups. There is little doubt that both the productivity and safety of the demonstration mine improved following the time of the intervention. The average productivity and safety of the other mines in the industry did not show similar improvements. There is also little doubt that productivity and safety at the Texasgulf Mine have remained at this high level or improved still further since the intervention. To what extent this improvement is directly attributable to the structured management training program 5 yr earlier, or is indirectly derived from the training is more difficult to say.

The mine's managers believe that the training improved both safety and productivity and that the production and safety records support this conclusion. According to persons interviewed, management saw the need for change; the training program provided the method. Given the many other factors that affect the safety and productivity of a mining operation, it is truly remarkable that these short training procedures seem to have made so large a difference in the mine's performance. It is even more remarkable that these gains apparently continued unabated for at least 5 yr. This study should provide considerable encouragement to management trainers in showing that the effects of short and relatively inexpensive structured training programs can have substantial and long-lasting effects.

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MANAGEMENT CONSIDERATIONS IN REDUCING THE ALERTNESS PROBLEM AMONG MINE EQUIPMENT OPERATORS

By Jon A. Wagner[1]

ABSTRACT

This paper discusses the alertness problems experienced by operators of large mobile mine equipment. First, background literature is reviewed, which describes the theoretical mechanisms that link various personal and work-related factors to impaired alertness and accidents. Second, the results of two mine equipment operator surveys are reported, which focus on causes of impaired alertness and possible means of alleviating the alertness hazard. Last, recommendations are made, based on the surveys, as to how the work-related tasks, environment, and rotation schedules can be modified to improve worker maintenance of alertness. It is expected that the improvement of alertness levels among mine equipment operators will result in a safer, more productive mining industry.

INTRODUCTION

Mine equipment operators – whether they be situated on the surface or underground – perform a steady flow of excavation or haulage activities that are the lifeblood of the mine. These jobs can be exciting and challenging to a new worker, but often become repetitious and boring for a more experienced worker. However, even the most conscientious equipment operator is faced with periods of boring repetition. Management thus is faced with a number of potential problems, especially when workers report difficulty in remaining awake or staying alert on the job. Consequences of such situation may include an increase in accidents, a decrease in productivity, and a decline in job satisfaction. It is, therefore, in the interest of both management and workers to understand the conditions that lead to impaired alertness, and to explore ways in which alertness problems can be prevented or alleviated.

The Bureau of Mines is currently performing research towards understanding and improving the most serious alertness problems in mining operations. A first step in this research is to characterize the mine equipment operators' perceptions of their alertness problems. To this end, two groups of mine equipment operators (N = 57 and N = 73) were surveyed. This paper summarizes the salient results from those surveys and discusses management's role in maintaining the alertness of mine equipment operators, as indicated by these results.

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SCOPE OF THE PROBLEM

For many years the Bureau has been concerned about the number of fatalities and disabling injuries suffered by operators of powered haulage equipment used in surface mining operations. An analysis (*1*)[2] of fatalities occurring in surface metal and nonmetal mines during the 1972-75 period showed that 29 pct occurred in the performance of haulage operations. Haulage trucks were involved in 75 pct of the haulage accidents that resulted in the deaths of 73 truck drivers. Miller (*2*) reports that in 1973 alone, accidents involving haulage trucks at metal and nonmetal mines resulted in 24 fatalities and 643 disabling injuries. Adkins (*3*) studied the haulage truck related fatal and nonfatal injury experience during 1978 and 1979. The study shows that haulage truck accidents occurring on the haul road and at the dump site account for the majority of the fatal and nonfatal injuries. These injuries are the result of the operator's vehicle colliding with other moving equipment or operating haulage trucks that rolled over.

A review of Mine Safety and Health Administration (MSHA) reports of the injury experience for all surface metal mining operations in the Nation for the 1978-82 period indicates that personnel involved in powered haulage activities continue to experience one of the highest number of fatal and nonfatal injuries of all job classifications reported. Table 1 compares the injury and lost workday experience of powered haulage with seven other accident classifications; powered haulage greatly exceeds the other major classifications. Table 2 compares the injury and lost workday experience of truck drivers with equipment types similar to those included in this study. The data show that drivers experience a greater number of fatalities and disabling injuries and a greater number of lost workdays.

Table 1.—Injuries and lost workdays at open pit mines, by accident classification, at metallic mineral operations in the United States, 1978-82

Accident classification	Injuries			Lost workdays	
	Fatal	NFDL	NDL	Fatal	NFDL
Powered haulage	18	545	160	108,000	36,672
Slips or falls of persons	2	1,127	363	12,000	32,275
Handling materials	2	1,344	989	12,000	27,005
Machinery	5	1,127	363	30,000	16,188
Hand tool	0	376	653	0	6,497
Electrical	9	43	16	54,000	5,099
Fall of face or highwall	1	9	5	6,000	3,294
Explosives	1	4	0	6,000	70

NDL No days lost. NFDL Nonfatal days lost.

NOTE.—1 fatality is charged 6,000 lost workdays, by definition.

Table 2.—Injuries and lost workdays at open pit mines, by occupation at time of injury, at metallic mineral operations in the United States, 1978-82

Occupation	Injuries			Lost workdays	
	Fatal	NFDL	NDL	Fatal	NFDL
Truck driver	7	576	157	42,000	23,967
Dragline, crane or shovel operator	1	117	56	6,000	7,750
Drill operator	1	179	54	6,000	5,210
Bulldozer or mobile equipment operator	2	250	105	12,000	5,164
Front-end loader operator	3	87	45	18,000	1,075

NDL No days lost. NFDL Nonfatal days lost.

NOTE.—1 fatality is charged 6,000 lost workdays, by definition.

ACCIDENT CAUSATION FACTORS

When one looks for the underlying causes of the accidents involving haulage trucks, it is apparent that operator error and not defective equipment is the major contributing factor. Operator error or human error is often caused by lack of alertness, fatigue, drowsiness, preoccupation with personal and family problems, and other operator concerns. Shiftwork is suspected as a major underlying factor contributing directly and indirectly to human error.

Miller (*2*) suspects that operator error was the primary cause of the accidents he studied. Hulbert (*4*) reported that ". . . a major cause of haulage truck accidents that resulted in fatalities and injuries is driver inattention, or lack of alertness." Hulbert grouped the underlying causes of driver inattention or lack of alertness as being task and nontask related.

The task-related factors include (a) lack of stimulation of the driver because the driving task is highly repetitive and (b) rotating shifts at a frequency that does not allow the person to adjust to the new work schedule or shift. The nontask-related factors include loss of sleep; disruption of circadian cycle; food consumption; use of alcohol, stimulants, or restorative drugs; temporary social and family related trauma; and highway hypnosis. Here it is apparent that such factors are not easily separated, but are indeed interrelated.

In a paper presented to a group of mine safety and mine management personnel, Schuler (*5*) indicates that rear-end collisions involving large haulage trucks are caused by many factors, but human factors such as falling asleep while operating the truck and lack of alertness because of distraction, fatigue, mental strain, and use of medicines, drugs and/or alcohol, are of prime importance. Decreased alertness or unalertness is cited as the prime factor involved in rear-end collisions. At the mine cited in the report, the most serious accidents occurred during the night shift, because the operators had trouble staying awake (one was actually napping) while operating the trucks. The study states that other mines in the area report similar experiences. No mention is made of the numerous near accidents, which are suspected to occur with greater frequency than an actual accident, because of driver unalertness.

Research into the cause of highway traffic accidents estimates that 35 to 45 pct of all single vehicle accidents are due to fatigue (*6*). According to Ferguson (*7*), fatigue is a complex biological phenomenon and is manifested in varying degrees in drivers operating over long distances.

[2]Italic numbers in parentheses refer to items in the list of references at the end of this paper.

Fatigue reduces the perceptual element and causes an increase in reaction time. Mental fatigue brought about by extended hours of driving is described as a diffuse sensation of weariness–a function state between alarm and sleep that leads to disordered concentration, reduced alertness, and increased sleepiness. Of the many causes of medical unfitness to drive a motor vehicle over long distances and quick turnarounds, fatigue ranks high.

OPERATOR ALERTNESS

A dictionary defines alert as being (a) watchful and prompt to meet danger or emergency and (b) quick to perceive and act. Unalertness is the antitheses of alertness.

Surry (*9*) compares the lack of alertness with the phenomenon of the eye looking at an object but not seeing it; the information the eye is receiving is blocked or ignored by the conscious mind. This phenomenon is the subconscious blocking of the information because all information inputs to the mind require enormous processing in the brain; in this case ". . . the brain seems to be generally less receptive and behaves as if in a sleep-like state."

In a state of alertness, the mind seems to be aware of many details in the environment and the person responds quickly to given situations. Hulbert (*4*) indicates that the lack of alertness on the part of the haulage truck driver ". . . is a state of mind in which the driver is unable to respond appropriately to an unexpected situation, or is unable to make appropriate steering corrections in time to maintain his truck on the correct pathway." An individual can range from being fully aware of environmental activities to being completely asleep, from quick response to no response to environmental events.

In the study conducted for the Bureau (*4*) to evaluate monitoring systems to detect the unalertness of drivers, eight mines were visited. The researchers interviewed mine managers, safety personnel, drivers, and maintenance personnel to determine the extent to which lack of alertness was involved in haulage truck accidents. The safety personnel and truck drivers admitted that failing to be fully awake and being unalert, especially on night shift, contributed to the accident potential.

Hulbert cited a number of task-related factors that were felt to be conducive to driver unalertness. The effect of these factors are summarized in this way (*4*): "There is a combination of a simple easy-to-drive truck, operating at low speeds, in very light traffic, in a high-level noise environment, in a sparse, uninteresting terrain, with few, if any breaks when the driver leaves the cab, and work shifts typically are changed every few weeks; all of which tend to result in drivers becoming less alert than they must be in order to cope with the driving tasks."

The report further states that ". . . anecdotal information given informally in conversations indicates that maintaining driver alertness is a matter of concern and that unreportable accidents and near accidents are occurring as often as once or twice on every shift due to less of alertness on the part of the haulage truck operators. In addition to actual crashes or near crashes, there are frequent occurrences of drivers going to the wrong place, losing their way, "blindly" following the truck ahead of them to an unwanted location and suddenly "awakening" to realize they had been in a semi-alert condition for many minutes while driving."

McDonald (*10*) feels that haulage truck drivers are unalert because of the routine nature of the haulage job and lack of stimulation afforded to the driver. This leads to boredom and sleepiness. Boredom (*11*) is ". . . the feeling accompanying the tendency to revert to restriction of attention to inadequately motivated tasks." In other words, a bored person restricts his or her attention to the task at hand. Boredom is produced by repetition (of monotonous tasks), fatigue, depression, and compulsion; daydreaming is one of the ways to cope with boredom.

McDonald (*10*) also feels that lack of alertness is aggravated in truck drivers who work on rotating shifts. Working on shifts that rotate on a weekly basis does not provide the time for the person to physiologically adjust to the new rest and sleep schedule. Because of this, drivers are out of phase–having trouble staying awake while on duty and unable to sleep while off duty.

The effect of shift work on the human circadian rhythm has been studied extensively. This effect is aptly summarized in the following statement by Ehret (*12*) ". . . the reason shift work, and in particular rotating shift work, leads to fatigue, less-than-optimum job performance, worker dissatisfaction, accidents and increased health problems is because shift work is dyschronogenic. This means that shiftwork . . . upsets circadian rhythms, the daily, natural body rhythms that must be reasonably well maintained in order for people to function well on and off the job."

In sum, human error has been associated with the cause of approximately 85 pct of mine accidents (*13*), and lack of alertness has been implicated as the single most important factor in human error accidents (*2, 14*). In the mining industry, the safe behavior of equipment operators is of particular concern, because their accidents are often very severe and can result in injuries, fatalities, and damage to expensive equipment.

METHOD

The objective of this study was to gain insight from experienced mine equipment operators regarding their perceptions of certain factors that may contribute to sleepiness and impaired alertness on the job. Specifically, the focus of this effort was to further explore the relationship between alertness and various shift rotation schedules, the adjustment to various schedules, the effects of job characteristics, and some coping strategies used by these workers. Based on the equipment operators' responses to survey questions, it is hoped that further insight can be gained as to how impaired alertness is caused and how it may be treated and prevented.

Surveys were administered to several independent groups of mine equipment operators to obtain data for this study. Two mining companies administered questionnaires to their employees (total of 40 miners) and a similar questionnaire was used by the Bureau to interview seven other miners contacted through local labor unions in the Tucson, AZ, area. These data were compiled and reported by the University of Arizona under contract to the Bureau (contract H0245001, "Shift Rotation Data on Driver Alertness From Large Mobile Mine Equipment Operators"). Through a second Bureau contract (contract S0231056, "Basic Hauling Truck Driver Alertness Data," with International Mining Consultants), seven groups of surface mine equipment operators were surveyed. Each group consisted of nine operators of a particular category of equipment (large trucks, small trucks, loaders, shovels, etc.) and the surveys were specific to equipment type, operating practices, and occupation.

Most of the results presented in this paper are derived from data contained in the University of Arizona report. The average age of these miners was 40.7 yr. Of the 57 miners, 50 were male. The average age of the subjects in the International Mining Consultants report was 44 yr, with 16 yr of mining experience. All of these respondents were male.

Although the survey techniques and questions differed between groups (no more than nine individuals received identical questionnaires from the Bureau), the results are compatible and support the same conclusions. Specific questions in the surveys were related to the demographics of the workers, drug use, work experience, shift rotation, alertness, naps, sleep length, and sleep quality. In addition, survey topics included health habits, work information, equipment design, work breaks, beverage consumption, accidents, highway hypnosis, and environmental concerns.

RESULTS

It should first be noted that both populations surveyed had the following pertinent characteristics: (1) the vast majority worked on rotating shifts, (2) most respondents drove haulage trucks, (3) most respondents worked in large surface mines, (4) no respondents worked underground, and (5) the lunch breaks referred to in these surveys are 20 to 30 min in duration.

WORK AND REST SCHEDULING FACTORS

Impaired Alertness and Boredom

The question, "Do you **ever** have a problem with alertness on the job?", is considered the key question in determining whether operators felt they had an alertness problem. Of 55 respondents, 35 (64 pct) indicated they did have a problem. These respondents characterized their lack of alertness as being the result of the following factors, in order of response frequency: "cannot adjust to shift rotation," "boredom," "lack of adequate sleep," "it is difficult to sleep during the day," "work is monotonous and repetitious," and "cab is too hot." The shift rotation factor was the most commonly perceived problem, and it maybe tied to the problems of obtaining adequate sleep.

This survey also found that 79 pct (45 of 57 respondents) became bored while operating their equipment. When asked to cite the shifts during which they experienced boredom, 26 pct cited the day shift, 32 pct the evening shift, and 42 pct the night shift. This suggests that boredom is the most prevalent during night shift and the least prevalent during day shift.

Time of Day

Respondents were asked whether they could identify particular periods within each shift when they felt prone to being less alert. Only 30.5 pct were able to identify such a period during day shift, 56.4 pct in the evening shift, and 88.2 pct during the night shift. This indicates that the respondents were more aware of alertness problems during night shift than during the other shifts. The time-of-day effect is further delineated by the question and replies in table 3. Table 3 shows the greatest alertness hazard occurring in the late night hours, followed by the early night shift and day-shift postlunch dip at 1 p.m.

Another time-of-day element in impaired alertness is the fatigue factor. The question and responses in table 4 indicate that a greater number of persons are aware of the drowsiness problem during the night shift, and these persons become sleepy quite early into the night shift. Although it is more pronounced at certain times, drowsiness appears to be a problem for a large number of persons on all shifts.

Table 3.—Response to "what time of day are you most susceptible to drowsiness, inattention, or impaired alertness," percent

Day shift:	
8:00 a.m. to 12:00 m.	10
1:00 p.m. to 2:00 p.m.	17
3:00 p.m. to 5:00 p.m.	8
Evening shift:	
6:00 p.m. to 8:00 p.m.	1
9:00 p.m. to 11:00 p.m.	5
Night shift:	
12:00 p.m. to 3:00 a.m.	17
4:00 a.m. to 7:00 a.m.	42
Total	100

Table 4.—Response to "how soon after starting each shift do you start feeling drowsy"

Shift	Av time into shift, h	Respondents
Day	4.54	25
Evening	5.18	32
Night	3.48	48

Rotating Shifts

One key question asked if working on rotating shifts contributed to a lack of alertness on the job. Sixty-nine percent (35 of 51 respondents) answered yes and 31 pct answered no. A possible connection between alertness and sleep quantity during work on rotating shifts is addressed by three questions. First, when asked if they felt they got adequate rest at home while working on rotating shifts, 50 pct answered no. Next, the miners were asked how much

sleep they got (see table 5). The responses in table 5 suggest that persons working on the night shift experience the greatest variability in hours slept, and that they got less sleep on the average. This represents a sleep deficit of 14 pct, when compared to persons working on either day or evening shifts.

Table 5.—Response to "how many hours of sleep do you normally get at home while working on rotating shifts"

Shift	Time slept, h		Respondents
	Range	Average	
Day	5.5- 9.5	7.25	55
Evening	5.0- 9.0	7.29	50
Night	3.0-11.5	6.23	48

The third question of this series inquired about the number of hours of sleep the respondents felt they normally needed. The number of hours ranged from 4 to 10, but the average hours of sleep needed was 6.97. This is 11 pct more sleep time than the average hours slept by the worker on night shift.

Shift Changes

The respondents were asked to identify the shift rotation schedules that were hardest and easiest, respectively, on their ability to maintain their alertness on the job. Their responses are tabulated in table 6. From table 6, one can calculate that 83 pct of the respondents to the question found that shifting to night shift from either day or evening shifts was hardest on their alertness. Another calculation shows that 68 pct found shifting from day to evening and from evening to day was easiest for them. It should be noted that most people find shifting from day shift to night shift is the hardest change, and that no one finds this same rotation to be the easiest.

Table 6.—Response to "which shift changes are hardest and easiest on your ability to stay alert"

Shift change	Hardest	Easiest
Day to evening	1	19
Day to night	23	0
Evening to night	16	6
Evening to day	3	13
Night to day	3	1
Night to evening	1	8
Total	47	47

Table 7 is somewhat similar but it focuses on sleep habits rather than alertness. Responses to the questions correlate well with the responses to questions about shift change and alertness. Seventy percent of the respondents found that rotating to night shift from day or evening shifts was hardest on their sleeping habits, and 67 pct found that rotating from day to evening or from evening to day posed the least hardship on their sleeping habits.

Table 7.—Response to "which shift changes are hardest and easiest on your sleeping habits"

Shift change	Hardest	Easiest
Day to evening	3	17
Day to night	20	1
Evening to night	12	4
Evening to day	5	14
Night to day	5	2
Night to evening	1	8
Total	46	46

An important question is can workers adapt to a new shift over time, or do they instead build up a fatiguing sleep deficit that tends to nullify any adaptation of their biological rhythms. Table 8 offers some information on this subject. The responses indicate that an adaptation occurs for the majority of workers on a new shift, with only about one-quarter of the workers becoming maladaptive. It seems apparent that this general population may be best suited to shift schedules that allow relatively long periods of time between shift changes.

Table 8.—Response to "do you have more trouble with alertness on the first days or the last days of a shift cycle," percent

Response	
First few days	73
Last few days	27
Total	100

Asleep on the Job

Of 57 respondents, 32 (56 pct) admitted to taking catnaps during work. Further information is provided in table 9. Of those who catnap while at work, most do not do so during the day or evening shifts. However, of the workers who catnap, 97 pct take one or more catnaps during the night shift. Of the 32 respondents who indicated they catnap in the night shift, 4 admitted to catnapping 9 to 18 times per shift. When asked how rested they felt after taking catnaps, 79 pct of the respondents indicated that they felt rested, 12 pct did not feel different, and 9 pct felt less rested or more sleepy.

Table 9.—Response to "if you take catnaps, how many do you usually take on a shift"

Shift	None	1 or more
Day	20	10
Evening	16	15
Night	1	32

Asleep During Breaks

When asked if they usually slept during their lunch periods, 35 of 55 respondents (64 pct) replied in the affirmative. Of the 44 lunchtime sleepers, 34 (77) pct indicated they slept during the night shift lunch break; 14 pct and 9 pct slept during their lunch periods on day and evening shifts, respectively. The relatively high number of night shift lunch-break sleepers shows the unusually high value placed on rest, especially when considering the attractive alternatives of eating a meal or conversing with coworkers.

Asleep at the Wheel

A most serious question concerns the occurrence of asleep at the wheel episodes (see table 10). Table 10 shows that nearly 80 pct of the heavy equipment operators admitted to falling asleep at the job at least once during each night shift. The survey also reported that five respondents admitted to falling asleep as many as 9 to 18 times per night shift.

Table 10.—Response to "while operating your equipment, how many times per shift do you catch yourself falling asleep"

Shift	Never		1 or more	
	No.	pct	No.	pct
Day	32	62	22	38
Evening	27	55	22	45
Night	10	21	38	79

PERCEPTION PROBLEMS AND ACCIDENT CAUSATION

Highway Hypnosis

Highway hypnosis is a form of trance induced by external conditions such as monotonous road scenery, constant noise of the engine, repetitious vibration patterns, and extended driving periods at constant speeds where physical action is minimal. To assess the recognition of this phenomenon by the operators, a number of questions were posed.

Fifty-three percent of the drivers indicated they had experienced hypnosis while operating their equipment. Most of them experienced highway hypnosis on night shift while driving over long distances (more than 10 min on one leg of a haul). Hypnosis most commonly occurred during the middle or toward the end of the night shift. When asked about hypnotic conditions drivers who had experienced hypnosis responded as shown in table 11.

Table II.—Response to "what condition leads to hypnosis"

Condition	
Constant noise	29
High temperature in cab	25
Constant driving	22
Same scenery	20
Constantly looking at road	19
Long drive uphill	18
Prolonged driving	17
Vibration	13
Eating	3

The next question asked (table 12) attempted to correlate the number of hypnotic episodes with the shift in which the events occurred. The data suggest that not as many people experience highway hypnosis during the day shift as in the night shift, and operators experience increasing episodes of hypnosis in a progressive manner while working day, evening, and night shifts, respectively.

Table 12.—Response to "how often do you realize that you have been driving your equipment but you don't remember the events of the past few minutes"

Shift	*Respondents*[1]
Day	15
Evening	22
Night	36

[1]Answering more than once per shift.

Accidents

Of 56 respondents, 37 (66 pct) indicated they had been involved in one or more accidents. Where specific accidents and shifts in which they occurred are mentioned, the accidents occurred as follows: 20 on day shift, 13 on evening shift, and 17 on night shift.

When asked if any of the accidents were caused by the equipment operators' lack of alertness, 13 of 36 respondents (36 pct) answered in the affirmative. In addition, 47 of 52 respondents (90 pct) thought that working rotating shifts increased a person's chances of having an accident. The question in table 13 addresses the reasons why an alert driver may avoid accidents.

Table 13.—Response to "would an emergency situation, such as a front tire blowout, be handled better by a driver who was more alert," percent

Response:	
Yes	96
No	2
No effect	2
Total	100
Explanation:	
Better reflexes	66
Anticipation	20
Other	14
Total	100

CONCLUSIONS FROM SURVEYS

Two-thirds of the respondents indicated that lack of alertness is a problem. Over half of the respondents admitted to taking catnaps during work. It is, therefore, clearly reported that impaired alertness and sleepiness is prevalent during work. Of those workers who do catnap, most usually did it on the night shift, although it does occur to a lesser extent on the day and evening shifts. The percentage of workers who stated that they have regularly fallen asleep while operating equipment at least once during each workshift is highest during night shift duty (79 pct) and lowest during the day shift (38 pct).

As it has been shown, shift work, night work, and shift changes all have a discernible impact upon the alertness problem. Some effects of shift rotation include reduced alertness, chronic fatigue, sleep deficit, disruption of sleep and eating patterns, and disruption of social life. Also, it appears that (1) weekly rotation does not allow most operators enough time to adjust and feel normal, (2) shifting from day shift to night shift is hardest on alertness and sleep, (3) all adverse effects of shiftwork are greatest on the night shift, (4) the first few days of a new shift are the most difficult in which to maintain alertness, and (5) the period from 4 a.m. to 7 a.m. is the time in which equipment operators are most susceptible to impaired alertness.

Finally, it is also apparent that alertness can be maintained, or at least restored, by incorporating certain changes in the way tasks are performed and by modifying shift rotation schedules. Other survey data not discussed in this paper reinforce these ideas. In general, the respondents felt that the following changes would reduce the lack of

alertness problem: (1) allow operators to select the shift they prefer and remain on that shift continuously, (2) rotate shifts less frequently than once a week, (3) provide air conditioning, (4) allow operators to swap equipment to alleviate boredom, and (5) do not keep the haulage truck driver on the same haul route throughout the entire shift. In addition, operators rated getting out of the equipment, conversing with coworkers, and performing a variety of job assignments as being the most important activities in maintaining alertness.

MANAGEMENT CONSIDERATIONS

After reviewing this survey information, mine managers and safety directors may wish to consider whether their operators work under any of the same conditions as the operators surveyed. If so, managers should become more aware of the specific alertness problems their operators face. This can be accomplished through informal interviews or formal company or union surveys. If there are indeed reports of falling asleep at the wheel, difficulty in maintaining alertness, or even just excessive boredom, managers may wish to consider various changes that may prevent unalertness and accidents.

CHANGING THE NATURE OF THE JOB

According to the surveys, boredom, monotony, and repetition were named as important causes of impaired alertness. Also, constant driving, prolonged driving, and driving past the same scenery were often cited as conditions leading to hypnosis. To combat these problems, the survey respondents made a number of reasonable suggestions that may be implemented under the right circumstances. Following is a list of possible changes that may be made to job tasks, plus some apparent drawbacks to these changes.

1. *Allow operators to swap equipment during a shift.*–This action will undoubtedly result in at least a temporary increase in alertness, especially if a miner swaps equipment types, as well. For instance, a haulage truck driver would probably become highly alert after swapping his or her vehicle for a front-end loader. However, some potential drawbacks include the necessity of cross-training and the problem of seniority rights in union environments. Also, the equipment swaps should not require extra time or travel, but would likely do so unless the workers normally meet at a central point for lunch, maintenance, or production activities near midshift. Another potential problem is that certain jobs may require substantial practice on each shift before the operator can become optimally productive and operate in a safe manner; equipment swaps may not allow this. Last, supervisors may need to deliver instructions at least twice if equipment swaps occur. All in all, equipment swapping may be a reasonable means of maintaining alertness (and morale) as long as the operators are sufficiently versatile and productivity is not adversely affected.

2. *Vary the haulage routes of truck drivers throughout the shift.*–This action will ensure changing scenery, which will alleviate visual boredom. Also, route changes to and from high-traffic and low-traffic areas should provide some necessary mental stimulation. Drawbacks to this approach are that multiple haulage routes are not always available, especially in smaller mines with only one excavator working, and that supervisory control of haul route assignment changes may be difficult to maintain without two-way radio contact. An ideal situation is a minewide truck dispatching system, where haulage is monitored and controlled by a computer-sensor network, facilitating instantaneous route changes for purposes of efficiency. A system such as this is not only extremely productive, but operators now become "part of the game" and are able to view changes in scenery (*15*).

3. *Encourage brief exercise breaks whenever there are work delays or when workers become excessively sleepy.*–Often, a quick 5-min break whereby the operator disembarks from his or her equipment and takes a walk, runs in place, or does jumping jacks, may be enough to restore lost alertness. Relatively intense physical activity in fresh air, free from equipment vibration, will result in immediate increases in heart rate, metabolism, blood pressure, circulation, respiration rate, and alertness. Also, the energy surge brought about by exercise may last for a period of hours beyond the time of exercise. Such exercise may be particularly important for older operators whose general health problems include poor circulation and heart function. Of course, drawbacks to exercise breaks include operational problems (how can the operator be contacted if he or she is away from the radio?), disciplinary problems (how can abuse of breaks or excessive break time be avoided?), and logistical problems (where can an operator safely exercise in uneven, rocky, or muddy terrain?). In addition, some workers may be used to dozing off during work delays and may not be readily motivated to exercise. However, if exercise can be achieved without the aforementioned problems, increased alertness should result.

CHANGING THE JOB ENVIRONMENT

Many equipment operators are subjected to high temperature, constant noise, and detrimental vibrations during the full term of the work shift. Each of these environmental stressors can affect alertness, and workers themselves have reported difficulties related to them. Following are three ways in which the work environment can be changed to promote improved alertness maintenance and overall performance.

1. *Where needed, install adequate air conditioning and ventilation systems in the cabs of mobile mining equipment.*–Even though a slightly warm cabin temperature of 80° F may result in optimal performance for many operators, temperatures above this usually bring about tiredness and drowsiness. Conversely, cabin temperatures below 60° F can hinder concentration, coordination, and circulation. Therefore, the cabin environmental control system should allow a temperature range between 60° and 80° F, not only for operator comfort but for occasional blasts of "cold" or "hot" air to stimulate operators during times of drowsiness. Highway drivers often benefit from simply rolling down a window for a change in temperature; unfortunately, mine equipment operators do not always have this option, because of dust and/or other

contaminants or fumes in the mine air. The only real drawback to air conditioning is the initial cost. However, the potential benefits include improvements in alertness, safety, performance, comfort, and employee morale, especially in mines located in hot regions of the country.

2. *Break up the monotony of constant equipment noise by allowing the use of both one-way and two-way radios.* – One-way radios (receivers) and cassette players allow each worker to play the kind of music that stimulates him or her. Two-way radios give the operator the opportunity to know what is going on in the mine, as well as allow stimulating conversation in time of need. Both radio types provide important cues (music, voices) that can arouse and stimulate a drowsy mind. A logical concern is that such devices may draw attention away from the job at hand, or may lead to a situation where the operator is bombarded with too many sources of stimuli and becomes overstressed. However, given the nature of the job tasks revealed in the surveys, this stimulation is badly needed. Possible abuses of radio use include playing music too loud to hear warning signals, and the tieup of two-way radios, effectively preventing receipt of emergency radio calls.

3. *Decrease the levels of vibration and noise transferred to the worker.* – Excessive noise and vibration can bring about physical as well as alertness decrements. Constant loud engine rumble and cabin sway, especially during uphill climbs of trucks and locomotives, seem to present a definite alertness problem for drivers. To combat noise, the installation of acoustic insulation to engine and/or cabin compartments can reduce engine noise to more tolerable levels. Protective ear wear may also be encouraged. For vibration reduction, state-of-the-art adjustable seats utilizing hydraulic or pneumatic damping systems can eliminate most of the high-frequency vibrations before they reach the operator. (Unfortunately, low-frequency vibrations that sway the operator have not yet been eliminated by either state-of-the-art seating or equipment suspension systems.) Other than the cost of providing noise and vibration reduction in the operator cab, a realistic concern is whether such measures will provide the operator with too comfortable a station, thereby leading to decreased alertness. The operators themselves, of course, do not share this concern; however, more research is needed to determine if there are negative performance effects resulting from an extremely high degree of operator comfort.

CHANGING LIFESTYLES TO IMPROVE ALERTNESS

Though it is not deduced explicitly from the operator surveys, other research suggests that workers' lifestyles contribute heavily to their on-the-job state of alertness. Managers can promote healthier lifestyles through education and training, wellness promotion programs, and employee assistance programs. The following points illustrate the major components of a lifestyle that will allow an operator to function at his or her best on the job: (1) weight control and adequate nutrition, (2) cardiovascular fitness through aerobic exercise, (3) abstinence from drug and alcohol abuse, (4) abstinence from tobacco products, and (5) adequate quantity and quality of sleep. Of these five points, the importance of getting adequate sleep was most strongly supported by the operator surveys.

CHANGING THE WORK SCHEDULE

Many of the survey's questions and answers focused on the effect of the work schedule on operator alertness. As mentioned earlier, both shift rotation and night work in general were perceived to cause problems with alertness and sleep habits. To alleviate these problems, the respondents reported a desire to either lengthen the period of time between shift rotations or to allow the workers to select a shift and remain on that shift permanently. In each case, the respondents showed their belief that 5 to 7 days on a shift was inadequate for their adaptation, affecting both life on the job and life and rest at home.

The question facing managers today is, "what is the optimum work schedule?" In mining and other heavy industries, a myriad of schedules exist, each with its advantages and shortcomings. Unfortunately, few valid comparisons or carefully constructed research efforts have been made regarding the safety of work schedules in the mining environment. There are, however, laboratory data available that can supply theoretical guidelines for the design of work schedules. Some of the options to be considered are as follows.

1. *Lengthen the period of rotation to allow further adaptation to the new shift.* – For instance, rotate every 3 or 4 weeks instead of every week. One mining operation reported a high degree of success in terms of health, productivity, and satisfaction after switching from weekly to triweekly rotations (*16*). Shift rotation, by its nature, is fair in that it makes sure everyone works each shift the same amount of time. However, a longer period of time on each shift may give workers a more adequate opportunity to make plans and establish routines.

2. *Change the direction of rotation from backward to forward.* – Most shift rotation schedules now rotate backwards, meaning that the next new shift begins 8 h earlier, rather than 8 h later than the old shift. This backward rotation works against the human body's natural circadian (daily) rhythms, which tend to prepare a body for a forward rotation. Previous studies have shown that it takes twice as long for a body to adjust to a backward rotation versus a forward rotation (*17*).

3. *Allow qualified workers to work permanently on night shifts.* – Though most workers will probably not want to do this, the few who do will greatly decrease the number of workers who must otherwise rotate through night shift. It is important to remember, however, that permanent night shifters may feel isolated from the mainstream of activity, and such isolation can result in lowered morale. Also, the availability of moonlighting jobs is great for permanent night workers. For these reasons, management should be careful to choose competent, dedicated, and motivated workers for permanent night shift, and should pay extra attention to the managerial needs of such workers.

4. *Where safety is not a major concern, shorten the period of rotation to prevent any partial adaptation to nonday shifts.* – For instance, rotate every 1 or 2 days instead of every week. This system, called rapid rotation, is currently used in various forms in many European countries and is popular among the workers. Workers maintain their basic diurnal (day-active) rhythms while fighting through brief periods of night work. Fortunately, this makes a high quantity of prime social time available each week, without the constant feelings of fatigue that often characterize weekly

rotations. However, night work is subject to increased errors, as workers work through the alertness trough (1 to 5 a.m.) without the benefit of any partial adaptation. Thus, such a schedule should be practiced only among those occupations where safety is not an issue and increased night time error rates can be well tolerated. This may well be the case with certain office and clerical workers within the mining industry.

Of course, many other scheduling options exist, including the use of extended workdays (10 and 12 h), compressed workweeks (3 or 4 days), noncontinuous schedules (e.g., two 10-h shifts per day), part-time fill-in crews, noncrew schedules, the use of overtime, and five-crew schedules. However, the major parameters determining safety are the four previously listed.

Possibly more important than choosing the optimum work schedules for a mine is the manner in which this schedule is chosen and implemented. The process of schedule modification should educate and harmonize all interested parties. It might even be true that the so-called optimum schedule turns out to be the current one; but if the managerial interactions leading to the final decisions are constructive, rational, open, and informed, then employee relations will be enhanced as an important side effect. Such a schedule modification process should have a win-win-win scenario, whereby management, safety, and labor personnel all reap benefits from both the process and the improved schedule itself.

Anecdotal information derived from stories of both successes and failures in changing shift schedules provides some important points to remember when considering a schedule change. First, there is no universally optimal schedule. What works at one mine may not work in another because of different operational and human requirements. Second, once a schedule change is made, it is extremely difficult to make another change within a short period of time. Thus, the process of selecting a new schedule ought to be conducted with very careful considerations. Third, improved schedules may be met by worker resistance unless worker suspicions and fears are alleviated. In sum, the schedule selection process requires a methodology that is both systematic and likely to be accepted by the workers. Following are recommended guidelines for choosing and implementing the optimum work schedule for a mining operation. Note that the actual procedure will probably vary depending on size, needs, and problems of the particular company.

1. *Construct a committee made up of representatives from top-to-bottom management, safety, and labor.* – This committee should work openly, encourage participation from all potentially interested parties, and be semipermanent in nature. The remainder of the steps in the following procedure will be conducted via this committee. It is especially important that no particular group of workers or job classification be excluded from committee activities, because the excluded group will then resist any schedule changes that are recommended.

2. *Evaluate the specific on-the-job problems and needs of the mine's particular worker population.* – The optimum work schedule can only be designed when the characteristics of the specific population are known. To perform this evaluation, the shiftwork committee should examine accident records, health records, and productivity levels to see if any shift-related trends appear. Of special interest are accidents occurring on the first few night shifts, on the last few night shifts, and during the alertness trough from 1 to 5 a.m. Also, incidences of naptaking, sleeping on the job, and dozing off should noted. Health records, if available, may reveal excessive incidences of gastritis, diarrhea, or other digestive disorders, and depression, which are also clues of schedule-related problems. Productivity fluctuations during and between shifts should also be noted.

Next, informal interviews should be conducted with a sampling of workers to ascertain what general schedule-related problems are noted by the workers. From these interviews, a list of major concerns should become apparent to the committee members. At this point a survey can be given to the entire population that elaborates on the concerns of the workforce. For instance, if interviewed workers report various sleeping problems, a survey can specifically ask when these problems occur, how much sleep is actually attained, and what could be done to alleviate these problems. Later, after a new schedule has taken effect, the workers can be surveyed again to see how comparatively beneficial the scheduling change has been. A final step in problem evaluation may be to have willing employees keep diaries noting sleep times, meal content and timing, and mood variations through a full shift cycle. A health-care professional should then examine the diaries, note schedule-related problems, and possibly recommend immediate courses of action such as special diets or sleep strategies.

3. *Determine the social and operational requirements of the work schedule.* – It is necessary to determine, through the committee, the social and operational constraints to be considered when designing the new schedule. For instance, married workers may highly value having free time in the afternoons for family life; single parents may instead prefer to have day hours free to avoid child-care costs. Hunters and fishermen may be able to pursue their sport on short notice during any daylight hours; high school sports fans may instead strongly prefer to have afternoons free. Also, the increase in two-earner households makes the work schedule of the spouse an important consideration.

Operational requirements include number and timing of shifts required to produce a product and the limits on hours workers may work to fulfill legal or cost requirements. Because of high overhead costs, continuous furnace operation, low-stockpile capacity, or high production requirements, some mines must operate on a continuous, 24-h/d, 7-d/week basis. However, other mines or mine crews may need to produce less than continuously. These production requirements should be ascertained and made known to the shiftwork committee.

4. *Design alternative work schedules.* – Utilizing information about the human body, the needs of the workers, and the requirements of the operation, a number of alternative work schedules should be designed. No design should be thrown out as yet; each design may have a valid characteristic that can be eventually utilized. Schedules can be drawn companywide or departmentwide. During this stage, other mines and industrial companies should be contacted for ideas of how different schedules can be constructed. It is estimated that over 4,000 schedules are currently in existence, yet the best schedules are probably designed from scratch for the particular needs of a specific company.

5. *Evaluate the alternative work schedules.* – Each alternative should be rated according to the following criteria:

a. How compatible is it with human circadian rhythms?
b. How easily will it be accepted?
c. How well does it meet operational requirements?
d. How well does it generate social time, in terms of quality and quantity?
e. What are the labor costs associated with it?
f. Does it meet legal requirements for wages, hours, and salaries?
g. How simple is this schedule to remember?
h. How many weekends off per month are included?
i. How acceptable is it to the line supervisor?
j. How well does it blend with current seniority practices?
k. How much time does it allow for training?
l. How amendable is it for workers wishing to trade shifts?
m. How difficult will it be to cover absentees?

Each of the above questions can become quite complex, especially question a. Biological compatibility relates to the worker's ability to adapt to a new shift, maintain a high degree of alertness on the job, and get adequate rest between workshifts. Again, specific population characteristics are important to consider. For instance, younger workers (18 to 30 yr) may be able to function quite well with a relatively biologically incompatible schedule. However, older workers (45+ yr) may experience severe sleep, digestion, and alertness problems with the same schedule, because of common physiological changes (*18*).

6. *Choose the three best alternatives for further discussion and a committee vote.* – Once the committee has voted and chosen the most promising new schedule, the workers should be informed about the choice and polled to determine their willingness to try the new schedule for a trial period of between 6 months and 1 yr. A clear majority should show such a willingness. If some sections or departments of the mine are very willing to try the new schedule compared to others, it is better to implement the new schedule only among the most willing sections. If the new schedule is indeed better, word of mouth will sell it to the less willing sections at a later date.

7. *Once the new schedule is implemented, the effects of the schedule change should be evaluated comprehensively.* – Evaluations should take place after about 3 months (when the workers begin to get used to it) and again after about 9 months (after the "honeymoon" is over). Sources of data for this evaluation include accidents records, productivity measures, health reports, absenteeism-tardiness records, worker interviews, reissued surveys, and diary information. The shiftwork survey should elicit specific information about the new schedule's effect on sleep habits, alertness, job satisfaction, and social life.

8. *Inform the workers about the results of the evaluations.* – Workers need to know how the new schedule affects the overall cooperation, in both positive and negative manners. Only after such education occurs, can workers then make an informed decision about adopting or rejecting the new schedule. Without the big picture, workers may tend to overvalue their personal opinions at the expense of the rest of the workforce. Of special emphasis are overall workforce changes in sleep, diet, and alertness.

9. *After 1 yr on the new schedule, either the committee or the total mine population may vote to keep or reject the new schedule.* – In either event, the process of choosing and implementing an experimental schedule is not yet complete. First, after understanding the problems the workers have with the chosen work schedule, a training session should be offered by the committee on how they can best cope with the stresses of shiftwork. Such a training session may contain advice on how to obtain adequate sleep during the day, how to plan meals to prevent digestion problems and provide adequate energy, and how to incorporate social and family activities into a shiftworking lifestyle. Family attendance at this training session is strongly encouraged. Second, the committee should meet at least yearly to discuss complaints about the current schedule, discuss new developments affecting shift scheduling, and briefly assess the scheduling needs of the current mine population. As the worker pool experiences turnover, aging, and lifestyle change, the needs of the workers can indeed change quite drastically in a relatively short amount of time.

CONCLUSIONS

Though powered haulage-type accidents are prevalent in the mining industry, especially among haulage truck drivers, management has a number of options available to reduce this safety problem. One such approach is the reduction of human error, to which impaired alertness is a primary contributor. Mine equipment operators themselves report that job tasks, environments, and work schedules all impact operator alertness. Therefore, based on worker surveys and other scientific research, recommendations are made to alleviate the alertness hazards. By making certain job modifications via a rationale process, operator alertness can be enhanced and employee relations can be improved as an important side benefit.

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SIMPLE COMPUTERIZED DECISION-SUPPORT SYSTEM FOR MANAGING COAL MINE PRODUCTIVITY

By Robert F. Randolph[1]

ABSTRACT

This paper presents a simplified decision support system for improving coal mine productivity. The Department of Energy funded a study in which a production-function approach was used to model daily coal production at the most fundamental producing unit—the mine crew. The study shows that mine managers already have easy access to information that can help them explain, control, and predict production at the crew level. Computer-derived models were used to assess the relative effects of labor, technology, and environmental factors on the daily reported coal production of 81 mining crews at 7 underground coal mines in the eastern U.S. coalfields. Almost all of the data came from daily production foreman reports, which are routinely gathered by most mining companies.

Linear regression analyses were used to derive production models that accounted for a significant proportion of the day-to-day variation in coal production. This technique promises to become an inexpensive and useful management tool for detecting and diagnosing production problems, assessing the effectiveness of a change both before and after implementation, and isolating factors that lead to changes in production. Mine managers can readily implement this technique by using their daily crew reports and simple linear modeling software running on any available computer.

INTRODUCTION

All mines have a productivity problem. That is, no matter how productive their operation is, mine managers often wonder if productivity is as high as it could be and, if not, how it can be improved. Part of the problem is information—there is a great deal of information available to managers about their mine's productivity, but this information is not in a form useful for timely decisionmaking. Thus, managing mine productivity is an ideal problem for the set of information management tools loosely categorized as decision support systems. This paper will describe a Bureau of Mines research project to develop and test a simple statistical decision support system for understanding and controlling the factors that can affect mine production.

Statistical approaches to production management are neither new or unusual. However, the traditional statistical analyses used in mining usually approach the problem at a very distant, aggregate level of analysis.[2]

While these tools are often useful for following gross fluctuations, they are too blunt and unresponsive to deal with some of the most important production processes, those that occur on a daily basis within individual mine sections. An alternative method is to analyze events that occur daily and at the level of analysis of the individual mining crew. This is significant for several reasons.

1. By focusing on the crew and section level of analysis in explaining factors that affect coal production, influences can be detected that would have been obscured in an aggregate analysis.

2. Using systematic statistical modeling reveals the relative effects of different factors (e.g., labor, delays) on production. These effects would be difficult to detect in a less systematic "eyeball" perusal of the data.

3. This method of systematic analysis is new to the mining industry and can make use of previously underexploited sources of information. Prior to this study, data were collected on production recordkeeping practices of a sample of 26 coal mines. Although all of the studied mines maintained detailed daily production records from each section, none had a systematic method for using this information in their management decisionmaking.

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The specific features of this approach that make it a unique and valuable method for understanding group performance include

1. Using a single, concrete measure of performance: the number of tons of coal produced by each crew during each shift.
2. Using the production function technique as the intellectual tool for selecting an initial set of variables.
3. Relying on the cause and effect connections specified by the production function to predict how various factors will affect production prior to actually measuring the relationship.
4. Recognition that when a mine section switches from one production method (e.g., advance room-and-pillar mining) to another (e.g., retreat mining with recovery of the pillars), the production process changes fundamentally and each method should be analyzed separately.

The analytic strategy was derived from the production function, which is a basic management science technique for relating production inputs to production outputs. The dependent variable for coal mining output is *tons of coal* produced. The independent variables can be described under the traditional categories of *land*, *labor*, and *capital*. Land, in the coal mining context, refers to physical condition variables such as seam height, quality of roof, quality of runways, and so on. The labor variable includes things such as the number of workers present and the quality of labor in terms of skills, abilities, and motivation. Capital, in this context, refers to the technology and technological policies, including the type and quality of mining equipment and the related mining policies that specify how and when equipment is to be used.

METHODOLOGY

SAMPLE

Data in this report come from seven mines. Table 1 describes the mines in terms of size and location.

Table 1.—Description of mines

Mine	Employees	Location
1	180	Pennsylvania.
2	394	Do.
3	358	West Virginia.
4	440	Virginia.
5	207	West Virginia
6	442	Illinois.
7	444	Do.

DATA BASE

The data for this analysis are drawn primarily from production foremen reports. These are daily reports, filled out by the crew foreman, that include information on production, which crew members were present or absent, delay times and causes, physical conditions, and so forth. While each mine records information differently, all mines had information about production, delays, and physical conditions. The specific form of the data or the level of differentiation of the data differed by mine.

VARIABLES

Table 2 describes the major variables used in the analysis. The variable name is given in the first column. Columns 2 and 3 provide the operational form and the source of the data. Note that because the raw data were taken from the mines' own records, some variables were only available for a subset of mines. The variables themselves can be grouped into five categories.

The first category provides a measure of output (the dependent variable). This analysis primarily used total *tons of coal* mined by the crew during its shift as the principal measure. For mines 1 and 2, the variable was constructed from data on the number of shuttle cars loaded during the shift by the crew and the number of tons of coal associated with a loaded shuttle car in the various sections. For mine 3, the number of shuttle cars loaded was used as the dependent variable because of the lack of data about the conversion from loaded shuttle cars to tons of coal. In addition, the number of feet cut was tried as a dependent variable. However, the variability in seam height made this measure an even poorer measure of output than number of shuttle cars loaded.

The second category of variables comprises several measures of the labor input. *Crew size* was used to assess the amount of labor available during the shift. Mines 1 and 2 yielded even greater detail on this variable. They recorded crew sizes for both the prime crew and the general labor crew (hence the use of two crew size variables – prime crew size and general labor crew size). To account for idiosyncratic influences due to differences between crews, dummy variables for each crew were created.

The third category of variables, and perhaps the most important single group in explaining production variation, was that of delays in production. Several measures of delays, distinguished for the most part by the equipment that caused the delays, were used. (See table 2 for the complete list of delay categories.) Because mine 3 reported delays in finer detail, it was possible to use more delay categories. In addition, bolter delays were entered as two variables (with the exception of mine 2) in order to distinguish differing effects on output of bolter delays that resulted in a cessation of mining activity (direct bolter delay) versus bolter delays that did not result in a cessation of mining (bolter delay).

The fourth category was designed to account for the effects of the mine's physical characteristics. Two types of variables were used. First was a measure of the physical quality of the section as reported by the foreman. The form of this report differed greatly from mine to mine, but it usually took the form of an index number such as 0 = good and 1 = bad. Second was a dummy variable associated with each section, which was intended to account for the effect of general section differences on production.

The last category contains several control variables. To account for the impact of an accident on production, the dummy variable *accident* was used to mark the shift and crew in which the accident occurred. Finally, to reveal influences associated with working different shifts, the dummy variables *shift 2* and *shift 3* were used.

Table 2.—Summary of variables used in analysis

Variable name	Operational form	Source
Output variables:		
Tons of coal produced	Tons of coal produced or loaded shuttle cars times conversion factor.	Company records or created by analysts based on company records.
Number of shuttle cars loaded.	Number of shuttle cars loaded during shift, including rock	Company records.
Number of feet cut	Depth, in feet, of cut into seam	Do.
Labor variables:		
Total crew size	Number of all workers working as a unit at face (excluding supervisor).	Do.
Prime crew size	Number of workers running continuous miner, shuttle cars, and bolters.	Created by analysts based on company records.
Number of general inside laborers.	Number of workers (excluding supervisor) in crew not running continuous miner, shuttle cars, or bolters.	Do.
Dummy variable marking crew X.	1 if crew is X	Do.
Equipment delay variables:		
Length of time continuous miner was not operational.	Sum of delays associated with equipment that is part of continuous miner.	Do.
Length of time shuttle cars were not operational.	Sum of delays associated with equipment that is part of shuttle cars.	Do.
Length of time bolters were not operational but did not cause cessation of mining.	Sum of delays associated with equipment that is part of bolters and not associated with a cessation of mining.	Do.
Length of time bolters were not operational and caused cessation of mining.	Sum of delays associated with equipment that is part of bolters and was associated with a cessation of mining.	Do.
Length of time equipment was inside section other than miner, bolters, or shuttle cars.	Sum of delays associated with equipment other than miner, bolters, or shuttle cars.	Do.
Length of time equipment outside section was not operational.	Sum of delays associated with equipment outside section	Do.
Length of time other activities inside section occupied workers.	Sum of delays associated with nonmining activities in section	Do.
Length of time managerial activities occupied workers.[1]	Sum of delays associated with managerial activities	Do.
Length of time moving continuous miner within section.	Sum of delays associated with moving continuous miner within section.	Do.
Number of shuttle cars	Number of shuttle cars available for at least half the shift	Do.
Length of time loader was not operational.	Sum of delays associated with loader	Do.
Length of time associated with stopping or starting.	Sum of times associated with preparing to stop or start	Do.
Length of delays caused by lack of empties.	Sum of times associated with lack of empties	Company records or created by analysts based on company records.
Physical conditions:		
Quality of physical conditions of the mine.[2]	0-1 (good or bad), mines 1-5; 1-4 (good to bad), mine 2; 1-5 (good to bad), mine 4; delay in minutes, mine 3.	Created by analysts based on company records.
Control variables:		
Dummy variable marking section X.	1 If section is X	Do.
Dummy variable marking accident.	1 if an accident occurred during reported interval	Do.
Dummy variable marking shift 2.	1 if data are from 2d shift	Do.
Dummy variable marking shift 3.	1 if data are from 3d shift	Do.

[1]Includes scheduled lunch breaks, trips to and from face, and inspections.
[2]For mine 4, quality of physical conditions was actually 2 variables—bottom conditions and top conditions.

BASELINE MODEL

The baseline model represents the basic production function for an underground coal mining crew. It expresses the dependent variable (tons of coal) as a linear function of all the independent variables discussed previously. The purpose of this model is to estimate the relative importance of those input factors that directly affect production. The baseline model is basic in the sense that it incorporates several simplifying assumptions, specifically that the function is linear in form and that the same computed model is valid for all the sampled crews at a mine. The validity of these assumptions can be tested by comparing the baseline model with more complex models that do not make the simplifying assumptions.

The analytic strategy, then, was to begin with a basic production function. After the model was tested against the hypotheses, the next stage was to examine whether more complicated versions of the model provide better explanatory power. The additional analyses revealed no significant nonlinearities or crew-to-crew fluctuations and are therefore not reported here.

The basic model to be estimated was

Tons of coal = crew size + miner delay + bolter delay + direct bolter delay + shuttle car delay + inside equipment delay + outside equipment delay + other activity delay + managerial delay + number of shuttle cars + physical conditions + shift 2 dummy + shift 3 dummy + accidents.

The exact set of variables used, of course, varied from the preceding list according to their availability from mine to mine.

Table 3 presents the expected signs of the coefficients. The labor variable should have a positive effect on production. All the delay variables should have negative signs. Number of cars, an equipment variable, is positively related – having less than the regular two cars usually degrades a crew's production. The physical condition variable has a negative sign, which reflects the coding of that variable (0 = good conditions, 1 = bad conditions).

It is difficult to judge the effects of shifts, hence the positive and negative signs attached to these variables.

However, the existence of an accident is disruptive and should reduce production, hence the negative sign.

For some variables, it is possible to only hypothesize the *relative* magnitudes of the coefficients. For example, delays in the continuous minor *stop* the production of coal, while delays in one of the cars only *slow* the production of coal. So the effect of continuous miner delay should be greater than the effect of car delays. Similarly, direct bolter delay, which stops the continuous miner from advancing, has a greater impact than indirect bolter delay, which means the bolter is down but the miner is still producing.

Table 3.—Expected impact of independent variables on output

Variable	Expected effect	Variable	Expected effect
Crew size	+	Other activity delay	−
Miner delay	−	Managerial delay	−
Bolter delay	−	Number shuttle cars	+
Direct bolter delay	−	Physical conditions	−
Shuttle car delay	−	Accident	−
Inside equipment delay	−	Shift 2 dummy	±
Outside equipment delay	−	Shift 3 dummy	±

RESULTS

Table 4 presents the estimated models for mines 1 through 7. For each mine, table 4 shows the explained variance (R^2) and the regression coefficients for the input variables, the R^2 or percentages of explained variance for the majority of the mines are fairly comparable, ranging from 0.46 to 0.63. This indicates that the models' explanatory powers for the mines are similar, accounting for roughly half of the variation found in the dependent variable, output. The only exception is mine 3, where the dependent variable is different from that of the other models. This finding of a common R^2 across most of these mines is important. Consider the simple fact that the procedure for recording data and measuring variables differs across these mines. Yet when the model is computed across mines, there is a reasonable and similar fit for each mine. The form of the model is also similar for each mine: the signs of the coefficients and the magnitudes are in the predicted direction for most of the variables in most of the mines.

Subsequent analysis revealed additional commonalities across the baseline models. In cases where data were available, different models were generated from pillaring versus developmental miming crews, as was expected. Also, the introduction of the section variable, a surrogate for machinery and physical condition differences, makes a significant contribution to explaining variation in output. The introduction of the crew variable also makes a difference. When the section and crew variables are introduced together, the crew differences are important in three of the five mines where data were available.

These observations about similarities are important because they deal with the primary objective of this paper—to estimate models of crew productivity. The key finding is that one can estimate this model of crew productivity across very different mines and identify models that exhibit similar explanatory power. Further evidence for the robustness of this technique lies in the close correspondence between the hypothesized model and the observed relationships between real-life conditions and outputs.

Table 4.—Summary of baseline runs for all mines showing model coefficients

	Mine 1	Mine 2	Mine 3	Mine 4	Mine 5	Mine 6	Mine 7
N	3,659	2,565	1,162	1,289	2,327	2,170	1,829
R^2	0.54	0.63	0.29	0.53	0.50	0.46	0.49
Dependent variable	([1])	([1])	([2])	([1])	([1])	([1])	([1])
Independent variable:							
Total crew size	NAp	NAp	0.87	0.96	8.6	NAp	NAp
Prime crew	6.3	2.6	NAp	NAp	NAp	17.5	−12.3
Number of general inside laborers	5.9	1.7	NAp	NAp	NAp	17.9	1.3
Shift 2 dummy	2.3	−0.71	2.4	NAp	NAp	12.5	−8.8
Shift 3 dummy	4.8	1.2	3.2	−38.2	−2.8	16.5	15.5
Miner delay	−0.43	−0.25	−0.06	−0.58	−0.82	−1.7	−1.8
Shuttle car delay	−0.10	−0.05	−0.01	−0.12	−0.15	−0.67	−0.62
Bolter delay	−0.03	−0.05	−0.03	−0.32	−0.25	−2.2	−1.1
Direct bolter delay	−0.50	NAp	−0.02	−0.62	−0.70	−0.29	0.91
Inside equipment delay	−0.36	−0.23	−0.04	−0.63	−0.63	−1.3	−1.2
Outside equipment delay	−0.37	−0.26	−0.03	−0.35	−0.75	−0.68	−0.38
Other activity delay	−0.42	−0.20	0.01	−0.60	−0.79	−0.58	−0.40
Managerial delay	−0.55	−0.23	−0.04	−0.62	−0.97	−2.2	−2.2
Miner move delay	−0.36	−0.26	−0.01	−0.25	−0.82	−2.7	−1.8
Hours worked	NAp	NAp	NAp	NAp	NAp	82.8	62.7
Load delay	NAp	NAp	−0.01	NAp	NAp	NAp	NAp
Delay in preparing to stop or start	NAp	NAp	−0.01	NAp	NAp	NAp	NAp
Empty delay	NAp	NAp	−0.03	NAp	NAp	NAp	NAp
Wreck delay	NAp	NAp	−0.06	NAp	NAp	NAp	NAp
Physical conditions	−15.5	−26.2	−0.05	[3] −0.78 [4] −4.5	−35.5	NAp	NAp
Accident	−7.3	−7.4	NAp	20.6	−17.5	NAp	NAp
Number of shuttle cars	31.8	18.2	2.1	32.1	36.5	NAp	NAp
Constant	112.6	172.6	13.3	266.4	363.5	99.7	270.6

NAp Not applicable.
[1]Tons of coal produced.
[2]Number of shuttle cars loaded.
[3]Physical condition of bottom.
[4]Physical condition of top.

DISCUSSION

The purpose of this study was to develop a model of coal production at the crew level. While most of the research in this area has focused on explaining productivity changes at the industry level, the results from this study indicate that it is also valuable to focus on the basic production unit–the crew. Furthermore, the results show that one can estimate a general production function across a varied set of mines. While it is difficult to draw refined distinctions across the mines because of differences in data sets and operational procedures, the analysis has revealed a fairly robust model. The explanatory power of the model is respectable and similar across these different mining settings. Also, the hypothesized form of the model, originally specified in table 3, appears to be confirmed. That is, the hypothesized signs and magnitudes of the production function are consistent with the estimated models. Thus, similar results could be confidently expected if the model is transferred to other mining settings.

This technique complements the usual aggregate or "macro" approach. It also offers an alternative to conventional "micro" approaches to group effectiveness research–particularly traditional social-psychological theories. Variables such as cohesiveness and group interaction are the typical foci of group effectiveness studies. A review of that literature[3] indicates that the evidence showing the impact of these variables on productivity is equivocal, at best. Therefore, this paper proposes the production function model as an alternative approach. If the analyst still suspects social-psychological variables to be important, the crew variable can be added to the model as a convenient crew level surrogate for these variables.

While the explanatory power of the models appears stronger than that of other organizational studies of work groups, there were still portions of the variation in coal production that remained unexplained. Analyses of the regression residuals and possible reporting bias by the foremen were undertaken to explore possible additional sources of explainable variance. In addition, many other analyses, at a mine level, were performed to sort out issues in coding and representing data. These analyses did not substantially increase the explanatory power of the models and are not reported here. Also, the cost of doing these additional analyses is substantial, and additional investments of analytic time are prohibitively expensive relative to the increased ability to explain variations in production.

USING PRODUCTION MODELS AS A MANAGERIAL TOOL

The development of within-firm production models can be a very effective tool for improving productivity at the mine level. An informal examination of a larger sample of 26 mines and 17 companies revealed nothing resembling the proposed production modeling method, but many of the companies could have beneficially implemented this technique at minimal cost.

Most of the mines in the sample, *but not all*, keep daily production data. These data, generated at the crew level are typically aggregated to the section level. The most common types of data are *tons produced, tons produced per number of miners,* and the delay variables. These data are reviewed by the superintendent each day, with the most attention paid to tons produced. Some mines computer-tabulate this information so it is available on a weekly, monthly, or yearly basis, whereas some mines do nothing with the data. These production reports also typically limit their focus to tons per mining unit or tons per number of miners per unit. None of the companies studied issue reports that link the input (delays) and output (production). The delay variables are often recorded and sent to the head of maintenance without any mention of corresponding losses or gains in production. Matching the data on inputs and outputs is essential for using these data for effective decisionmaking.

Consider the following scenario: You are a mine manager and have before you daily or weekly data on production of coal in the typical report format. Assume that the data are at the section level. You observe that sections A and B produce the same amount of coal. You may well wonder whether they are equivalent producing sections and whether you can expect them to both produce the same amount tomorrow, next month, or next year. You cannot know for certain because of the failure to relate inputs to outputs. For example, if section A had poor physical conditions and produced as much as B, we could say A is more productive. If A were pillaring and B doing developmental mining, we would say A is less productive. If we say A is pillaring and working under poor conditions, A's relative productivity is harder to judge because pillaring and physical conditions have opposite effects on production.

The point is that there are a large number of variables (shift, delays, accidents) that affect production, and these inputs have a complicated set of effects on output. This paper asserts that solely looking at output without any formal model reduces the utility of production information as a valuable managerial resource. Or, to put it another way, the use of production models can prove to be a valuable managerial tool and an improvement over the current procedures for using production information.

There are two major ways in which the model procedure in this paper can be used as an effective managerial tool: as a diagnostic tool and as a tool for assessing change.

A DIAGNOSTIC TOOL

The production model introduced in this paper can be a new analytic tool for managers. It can serve as a powerful way to detect increases or decreases in coal production by crew or section. The way to do this follows. Think of any of the baseline models presented in table 4. These models represent the average production function for the crews at a mine. The models can be thought of as a set of weights for input variables that affect production. The use of the term "baseline model" implies that, given the type of technology and labor at a given time, this model is fairly stable and

[3]Goodman, P. S., E. C. Ravlin, and L. Argote. Current Thinking About Groups: Setting the Stage for New Ideas. Ch. in Designing Effective Work Groups, ed. by P. S. Goodman. Jossey-Bass, 1986, pp. 120-167.

representative of the production process in any crew at this mine. In a sense, this model is a standard by which future production can be judged.

A useful strategy, then, is to use this modeling procedure to evaluate future production. That is, for any time period a manger can enter the values of the input variables and multiply these by the coefficients. Using mine 1 as an example, if the manager wanted to assess production on a particular day, he or she would determine the delay times per machine and multiply these by the coefficients. So if there were 100 min in miner delay, the manager could use the model to predict a loss of 43 st ($100 \times 0.43 = 43$). To assess total predicted production, all of the products and the constant are added together. The predicted number of tons could then be compared against the actual amount produced.

If predicted production is found to be lower than actual production, that particular crew would have been more productive than expected. Similarly, if predicted production exceeds actual production, productivity would be lower than expected. Again, since the production model reflects inputs and output, the results of this analysis are much more interpretable than looking simply at output.

The preceding example uses the production model as a tool for analyzing variations in production. In that sense it is a diagnostic tool because it can tell if production is higher, the same, or lower than expected. Managers may want to use the model to establish a range of acceptable production for each section at their mines. If crew performance drops below the minimum value of the range, then remedial action may be necessary. Likewise, if a crew exceeds the top value of the range, special rewards may be in order.

There are other diagnostic uses of production modeling. For example, one can systematically assess the effect of accidents on production. The effects of absenteeism can also be evaluated. If it is assumed that variation in the labor variable is primarily affected by absenteeism, a logical question would be what would happen to production if absenteeism were reduced. This would be answered, for example, by changing the labor variable to reflect better attendance and then asking the model to show the predicted increase in production. The additional production represents the cost of the existing level of absenteeism.

A TOOL FOR ASSESSING CHANGE

Managers often introduce new programs to improve production. These programs might vary from a new training program to a new maintenance system. They assume that these changes will modify the production function of the mine. Simply looking at output changes before and after the intervention will not be informative for the reasons suggested previously in this paper. For instance, if a new training program was introduced and production increased by 5 pct after the training program began, simply looking at these output data might invite one to infer that the training program increased production.

However, it is known from this paper that multiple factors (e.g., physical conditions) can increase production and these factors are unrelated to the training. So, without controlling for these potentially confounding variables, it is difficult to know how to explain the 5-pct increase in production. Production modeling is ideally suited for this analysis because it statistically controls for the multiple variables that affect productivity. That is, it allows the manager to isolate the different factors (e.g., training and physical conditions) that affect the production of coal.

The following example shows how production modeling can be used to evaluate a managerial change. Assume that a mine manager has introduced a program for improving mining practices. The decisionmaker should analyze historical data to estimate a baseline model prior to making any changes and assume that an effective training program will improve productivity. These changes should be reflected in the production model, either in the constant or in coefficients. One simple test is to reestimate the model before and after the change and introduce a dummy variable for the period change. A significantly large coefficient for the dummy variable will provide some evidence on the effectiveness of the changes.

A more sophisticated method is to follow the initial baseline estimate with the introduction of daily input variables into the production model to determine predicted production for the change period. If the training has shifted the production model, the actual production for the change period should exceed the predicted production. A demonstration of this procedure was shown by Goodman.[4]

Given the increased utilization of computers in the mining industry and the availability of software, the task of constructing these production models is feasible. Most mines are already collecting the necessary data. Rather than continuing to fill out the conventional handwritten report, they could directly enter the data into a computer. In any case, the data can be easily input and fairly easily processed with existing software. The number of microcomputer software packages that include linear modeling functions is growing constantly. Most of these programs can be used to do the relatively basic analysis described in this paper, and many can analyze even more sophisticated models.

[4]Goodman, P. S. (ed.). Assessing Organizational Change. Wiley, 1979, 391 pp.

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